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Coastal Restoration Agreements Under Climate Change: Barriers and Enablers

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Abstract

Coastal ecosystems are becoming less resilient under climate (e.g., sea-level rise, warming, acidification) and human (e.g., urbanization, coastal hardening, and river regulation) pressures, forcing local communities to face increasing risk levels. This lack of resilience is linked to an adaptation deficit that can be recovered through restoration. Yet, restoration faces barriers related to governance, funding, technical practice, and social context. To overcome such barriers, the REST-COAST project has developed a framework that reckons with coastal restoration platforms and restoration agreements, supported by “enablers” that support the upscaling and implementation of restoration projects. The proposed agreements and platforms can effectively overcome barriers by embedding governance, technical, financial, and social enablers into the agreements among stakeholders. Tailored, place-based approaches foster collaboration, long-term adaptive management, and the scaling of restoration to address accelerating climate-driven risks. The proposed agreements build on hands-on restoration lessons, offering transferable insights for global coastal resilience.

Keywords: coastal ecosystems; restoration agreements; restoration platforms; barriers; enablers



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1. Introduction: Coastal Restoration Deficit, Barriers and Enablers

Coastlines and the communities that live behind them are becoming increasingly vulnerable under future climate scenarios. Rising ocean water temperatures and acidification, compounded by sea-level rise (SLR) are exacerbating the frequency and intensity of storm-induced damages [1–8] while decreasing the protection offered by coastal ecosystems [9–12]. Such a decrease is linked to an adaptation deficit in which the limited pace and scale of adaptation are considered to be key factors to explain the degradation of present coastal systems, which limit their capacity to adapt to increasing climate hazards. This deficit will be hard to bridge unless suitable technical, economic and management advances (in short, restoration enablers) are applied to overcome current barriers to restoration and its upscaling [11,13].

In response to climate change, in general, and SLR, in particular, many ecosystems provide resilient biophysical responses that allow them to evolve at a rate similar to climatic pressures, illustrated by wetland response under increasing SLR and temperature together with decreasing pH [14,15]. Salt marsh accretion and lateral expansion are driven by seasonal cycles of plant growth [16,17]. In sandy beach environments, longshore transport facilitates the movement of riverine solid discharges into nearshore processes [10,18]. Accelerating climatic and anthropogenic pressures are progressively limiting these biophysical processes and act as barriers that hinder natural coastal resilience. This resilience is further threatened by pollution, land reclamation, draining, and damming [19,20].

These and other typical human activities on coastal zones, linked to altered water, sediment, and nutrient fluxes, deliver socioeconomic benefits, but lead to artificial coasts that have lost, at least in part, their natural resilience to SLR and wave storms. This amplifies risks due to erosion, flooding and salinization, leading to vulnerable coasts that present high climate risk levels for present and future coastal communities. By way of illustration, more than 70% of beaches now face a negative sediment budget [21] leading to erosion, which is thus becoming a global problem. The combination of climate change and anthropogenic stresses have worsened coastal hazards, and 4.6% of the global population is expected to experience annual coastal flooding by 2100 [21].

This has created a need to protect coastal populations from erosion, flooding and other climatic risks under present and future conditions, which will grow to unacceptable levels unless suitable enablers are applied to fill the coastal restoration deficit at a rate commensurate with climate change acceleration. This challenge defines the core of the paper, which investigates how coastal risks can be curbed in the mid- to long-term through the implementation of coastal restoration agreements that combine the required technical, economic, social and governance enablers. These contracts aim to fill the present implementation gap by answering the following research question: how may restoration barriers and enablers be embedded in co-designed agreements to enhance restoration success? Drawing on the literature, existing restoration contracts in forest and river ecosystems, together with incipient work for coastal systems, will provide the basis to develop upscaled coastal restoration agreements, with supporting evidence from the pilot restorations carried out within the REST-COAST research project, developed as part of the European Green Deal.

2. Coastal Restoration Framing: Questions and Answers

2.1. Why Restore Coastal Ecosystems?

Coastal hazards have been traditionally addressed through gray infrastructure, designed and built within a top-down designed plan, as a reaction to short-term needs [22]. The mainstreaming of gray infrastructure is linked to its short-term efficiency in mitigating hazardous events, but future climate change scenarios predict events surpassing the static safety factors for which such gray infrastructure is built [10,21,23]. Updating

and repairing this infrastructure to meet future requirements presents significant costs and uncertain performance under prospective scenarios, often leading to the degradation of coastal ecosystems, weakening their ability to mitigate storm impacts [18,24]. This is exemplified in seawalls which provide short-term protection against waves and surges but lead to enhanced mid-term erosion when reflected waves increase longshore transport and produce wall toe scouring [25]. This has led to a shift in present coastal protection practice, favoring green or hybrid infrastructure as a more adaptive means of reducing coastal risks from increasing human and climatic stresses [26]. In addition, such green protection presents a lower carbon footprint for implementation and contributes to coastal blue carbon for climate mitigation.

Restored coastal ecosystems means they can become dynamic ecotones to offer supporting, regulating, provisioning, and cultural services. Restoration can align coastal protection with climate mitigation, illustrated by wetlands or seagrass meadows that provide efficient carbon sinks, a regulating service. For coastal adaptation to climate hazards, restored ecosystems can regulate shocks and stresses [27], where natural coastal dynamics provide a wide range of regulating services to curb natural hazards [21,23]. For example, beach profile adaptation, involving wetland and dune migration, enhances surge and wave attenuation and reduces land loss to sea-level rise. Subtidal habitats can cause localized shoaling, forcing wave breaking and reducing storm-induced erosion and flooding. Coastal vegetation and reefs enable sedimentation processes that result in accretion and higher adaption potential under sea-level rise [28]. Coastal ecosystems thus provide both abiotic and biotic services that reduce coastal hazards with a low carbon footprint and must be restored at a rate and scale commensurate with climate change.

2.2. How to Restore Coastal Ecosystems

The combination of anthropogenic pressures and changes to shorelines through traditional engineering have left coastal ecosystems degraded and unable to adequately provide their ecosystem services. However, ecosystems and their ability to deliver beneficial services [29,30] can be repaired through ecological restoration (ER), which is the “process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed” [31]. Effective ER should not only focus on the renewal of ecosystem services, but on the long-term increase in ecological integrity as well as on the benefits to society [32].

To decide on how to restore ecosystem services and societal benefits, an end-point must be defined to determine “restoration success.” Although it has been argued that it is hard to co-define a standard of success [32], best practices have been put forward [31,33]. The Society for Ecological Restoration suggests setting a target based on biophysical parameters and stakeholder goals [31,32,34]. This means that ER success will change depending on location, climate, and stakeholders involved.

In coastal ecosystems, ER can be accomplished across a range of interventions, where natural regeneration is the most passive form of restoration and assisted or active regeneration is the more active [32] approach. Ecological engineering belongs to a subset of active ER that aims to use combined adaptation strategies to efficiently meet the ecological and societal principles of ER through engineering practice [23]. Ecological engineering embodies a range of hard and soft interventions that incorporate conservation principles in the design and implementation of solutions, designed and implemented with the efficiency sought by engineering [35]. Examples of this include sand dune restoration as well as seagrass planting and wetland construction works. Ecological engineering can also be termed nature-based solutions (NbS), building with nature, or living shorelines, with minor and mainly theoretical semantic field differences [36]. Restoration success metrics in coastal environments have traditionally been defined by the measures associated with hard,

gray solutions such as seawalls or groins. Ecological engineering defines success metrics based on the dynamic goals of restoration projects, which often form a matrix of increasing protection, ecological integrity, and social benefit [21]. These restoration goals are ideally defined by a platform of collaborating stakeholders including coastal managers, scientists, engineers, and members of the local communities.

2.3. Which Barriers to Overcome for Restoration Success

Ecological conservation and restoration, not identical [37], have increasingly become a global policy topic as demonstrated by the United Nations' adoption of the Kunming–Montreal Global Biodiversity Framework (GDF) in 2022 [38]. Under this framework, member states have pledged to conserve 30% of land, freshwater, and sea areas by 2030. In the European Union (EU), ecological conservation and restoration first appeared in policy with the 1979 Birds Directive, and this was followed by the 1992 Habitat Directive [38]. These directives aimed to protect selected bird, flora, and fauna species by developing Special Protected Areas (SPA) and Special Areas of Conservation (SAC), respectively. The SACs formed an ecological network of over 27,800 sites, named Natura 2000. As of 2020, more than half of the areas and species covered by the bird and habitat directives faced unfavorable conditions. In response to the lack of success with the directives and the GDF, the European Commission developed the Biodiversity Strategy 2030 under the European Green Deal [37,38]. The strategy expands on the Natura 2000 network and aims to protect at least 30% of land and sea target areas by 2030. To make the strategy enforceable, the European Commission legislated the Nature Restoration Law (NRL) in 2024, which binds European Union members to the targets of the strategy [39].

Differences in EU member states and regional heterogeneity may hinder a comparable implementation of the New NRL. It should be noted that the NRL was approved in June 2024, and is entering into practice in coming years, so there is still a long way before comprehensive and representative analyses can be performed, even more so for inter-actor restoration contracts. Differences among EU member states in governance structures, long-term funding commitments, and expertise in large-scale restoration projects will hinder the derivation of quantitative conclusions on restoration effectiveness as a function of socio-ecological conditions until more data is available. Because of that, there are only preliminary results on coastal restoration implementation, which nevertheless show, from the work in coastal restoration platforms, an increase in the pace and scale of restoration agreements based on the proposed consensual approaches. In any case, the evolution of climate and human pressures and the new data that is beginning to be collected will affect these restoration agreements, which should be flexible enough to accommodate such an evolution.

While the NRL offers strong legislation on a regional scale to support restoration, restorationists will still face barriers to implementation from the national to the local level. In a review of restoration experts' experiences with project implementation, "insufficient funding, conflicting interest among stakeholders, and low political priority given to restoration [at the local level]" were identified as major barriers to restoration [40]. Thirty additional barriers were identified and grouped into six categories: financial, environmental, legal (including land ownership), planning and implementation, policy and governance, and the socio-cultural context [40]. These categories can be generalized into technical, financial, governance, and social barriers to restoration. The study found that the technical barriers to restoration were overshadowed by the financial, governance, and social barriers, stating that restoration would not be furthered in the EU until they are addressed [11,41]. Contrarily, practitioners identified effective restoration as a process that considers biodiversity, ecosystem function and ecosystem services with a goal

of reaching a self-sustaining ecosystem for a continued delivery of ecosystem services. Restoration success is, thus, based on an initial site assessment for design and deployment, supplemented by a continued monitoring and adaptive management for maintenance and sustainability [13].

2.4. Where to Implement Restoration Agreements and Platforms

While legislation is one tool through which ER is supported, it is not the only one since conservation and restoration agreements can be applied to overcome barriers and solidify enablers during the project planning, implementation, monitoring, and maintenance. Such agreements are most commonly seen in forestry restoration for carbon sequestration among other purposes, but they are also being formulated in other ecosystems [42,43]. The five main types of agreements can be grouped into: (a) “Conservation Concession Agreements” which develop lease agreements for land that organizations are then able to restore [42] (p. 449); (b) “Conservation Performance Payments” which are similar to concession agreements, but they create a payment for an ecosystem service as long as habitat protection or restoration outcomes are achieved; (c) “Carbon Agreements” which are common in forests and coastal environments, here termed Blue Carbon Agreements; (d) “Private Protected Area Agreements” which are parcels of habitat owned by a company or other private entity which are paid to conserve the parcel; (e) “Debt-for-Nature Swaps” which are contracts that purchase foreign debt in exchange for restoration efforts or conserved areas. In the field of restoration, long-term contracts are preferable to short-term ones, to ensure that monitoring efforts and adaptive management can be properly enacted [44].

These agreements can be supported by restoration platforms, aggregating all relevant stakeholders to promote consensus and long-term aims. These platforms help overcome barriers and secure enablers by capturing the dynamic nature of the protected ecosystems. They accommodate mechanisms for adjustment, setting parameters for how disputes may be settled [45], where dispute settlement and consensus building normally benefit from long-term agreements. Restoration platforms can be better bound by such agreements, which foster consensus among stakeholders based on limited uncertainties and explicit shared benefits. Coastal restoration agreements should define the barriers and enablers that must be addressed as a function of time and space, to ensure a sustained risk reduction and improved livelihood based on the delivered ecosystem services.

In coastal ecosystems, agreements should be first implemented in locations with high social and ecological vulnerability [46]. Such vulnerable locations can be identified by a combination of indices including the exposure of socioeconomic activities to coastal hazards, the recovery potential of coasts after a hazard, and the ability for a society to recover [47]. These locations’ vulnerability, from short- to long-time scales, can be ameliorated by implementing nature-based solutions, conveniently maintained to achieve a short- to long-term coastal protection aligned with climate mitigation.

Such a decarbonized coastal protection requires a governance system that is mature enough to coordinate policy, legislation, and administrative action to implement large-scale restoration projects [48]. Although agreements can be used to foster communication and knowledge building, they may best be implemented where there is a baseline, or willingness to collaborate on an effective co-design, implementation, and monitoring. This should lead to upscaled restoration, at a pace and scale commensurate with the projected climate change acceleration [11,46,49].

3. Systemic Restoration: River–Coast Connectivity and Dynamics

The delivery of coastal ecosystem services requires, given the progressive degradation of many coastal habitats worldwide [50–53], large-scale interventions that restore their

functions and structure. This implies reconnecting river basins to downstream coasts and recovering the natural dynamics of nearshore areas. When connectivity has been hindered for decades, such as is the case for regulated rivers or hardened coasts, restoring hydro-sedimentary flow regimes, ecological integrity, and sociological integrity may take significant time intervals [53]. Restoring partial connectivity and natural dynamics to preserve some of the benefits from the existing infrastructure has initially had a local effect on near field domains (local riverine or coastal area restored). The beneficial effect on wider spatial scales takes a certain time to spread, which goes from months to years, since the riverbed and margins need to recover the missing sand fraction, for instance. Restored freshwater and sedimentary flows produce a cumulative impact on riverine, estuarine and coastal habitats, which must be controlled to avoid overshoot and other undesirable effects, while monitoring their positive impact from the recreated functionality of the involved ecosystems. For instance, controlled floods return sediment transport first to the river domain and eventually to the receiving coast, with a time scale that depends on the extent of river and coastal stretches involved in the restoration. Using this example, river to coast connectivity will return solid transport towards the coast, but the amount and temporal interval will depend on the available freshwater volumes (affected by persistent droughts in some of the pilots), the level of incision in the main and tributary rivers (considering also the state of the margins) and the eco-morphological state of the estuaries that connect rivers and coast [53]. The synergies and tradeoffs associated with restoration [13] must be discussed and transmitted to all relevant social actors, presenting the alternatives to the services provided by existing infrastructure (such as electricity or freshwater access supplied by reservoirs and dams). To achieve a lasting socioeconomic engagement, it is key to balance infrastructure and ecosystem services, presenting them in coastal restoration platforms, where their evolution under co-selected future scenarios and shared benefits can be discussed. Ecosystem services delivered by a restored connectivity include flooding and erosion risk reduction, water quality enhancement, biological productivity [50,54], and coastal blue carbon (among the most efficient carbon sinks on the planet) [55]. These services, less well known than the beneficial effects of rigid infrastructure, are being promoted and discussed at the Coastal Restoration Platforms.

A systemic approach is therefore required, overcoming the current deficit in restoration implementation [11,56]. Available restoration evidence, from pilot interventions such as the ones in the REST-COAST project (<https://rest-coast.eu> (accessed on 30 September 2025)), demonstrate across a set of social-ecological conditions (Figure 1) how upscaled restoration can align coastal adaptation with climate mitigation through blue carbon, natural hazard reduction, biodiversity gains, and improved environmental status [11]. These nine pilot initiatives pave the way to implement landscape-scale restoration, combining river–coast connectivity with nature-based solutions to recover coastal resilience through natural sediment and nutrient fluxes.

The pursued restoration upscaling is based on overcoming current barriers by suitable “enablers” (Figure 2), which increases the scale and pace of the implementation, commensurate with the projected acceleration of climate change for the remaining decades in this century [50,57]. The pilot interventions were selected as they refer to a variety of coastal vulnerability hotspots, including deltas, estuaries, and lagoons over nine sites that sweep a large enough set of social-ecological conditions to facilitate deriving exportable criteria and metrics [11]. The targeted habitats are dunes (emerged coastal area), wetlands (intertidal area) and seagrass meadows (submerged area), under complex constraints for the integration of governance, social, economic, and technical requirements. The pilot restorations carried out have served to develop a set of enablers, based on best practices for active and passive restoration techniques, supported by business plans and financial

arrangements. Such an approach must be associated with a transformative governance, based on an increased engagement by all relevant coastal actors [55] to ensure sustainability.



Figure 1. Visual summary of the nine pilot restoration cases in the REST-COAST project. These pilots provide demonstrators on how to achieve coastal risk reduction and environmental quality under climate change, based on enhanced connectivity and dynamics for a sustained delivery of ecosystem services.

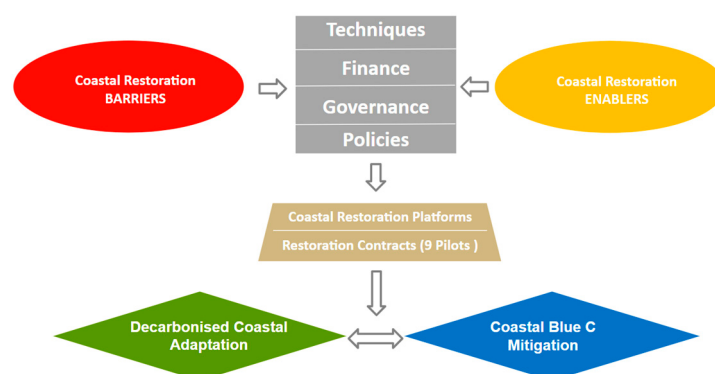


Figure 2. Conceptual diagram linking the proposed REST-COAST barriers and enablers. The application of these enablers to the three targeted ecosystem types serves to overcome current barriers against large-scale restorations, contributing to fill the present implementation deficit, projected to increase under climate change.

Restoration upscaling can only be deployed and maintained through continued monitoring from which key performance indicators, co-selected by all relevant stakeholders, can be evaluated as a measure of restoration efficiency and limits [58]. Monitoring must be carried out at sufficient resolution to characterize different ecosystem services, but also maintained for long enough periods, commensurate with the time required by some ecosystems to recover or develop (e.g., seagrass transplantation or passive restoration). Observations should be supplemented by numerical simulations that predict the short-term impact of storm events (Figure 3) and project the long-term evolution (Figure 4) driven by climate change. Such a combination of observed and simulated data enables an objective ranking of restoration interventions and their sequencing, providing quantitative information on feasibility, initial costs, maintenance expenditure and benefits from the delivery of ecosystem services.

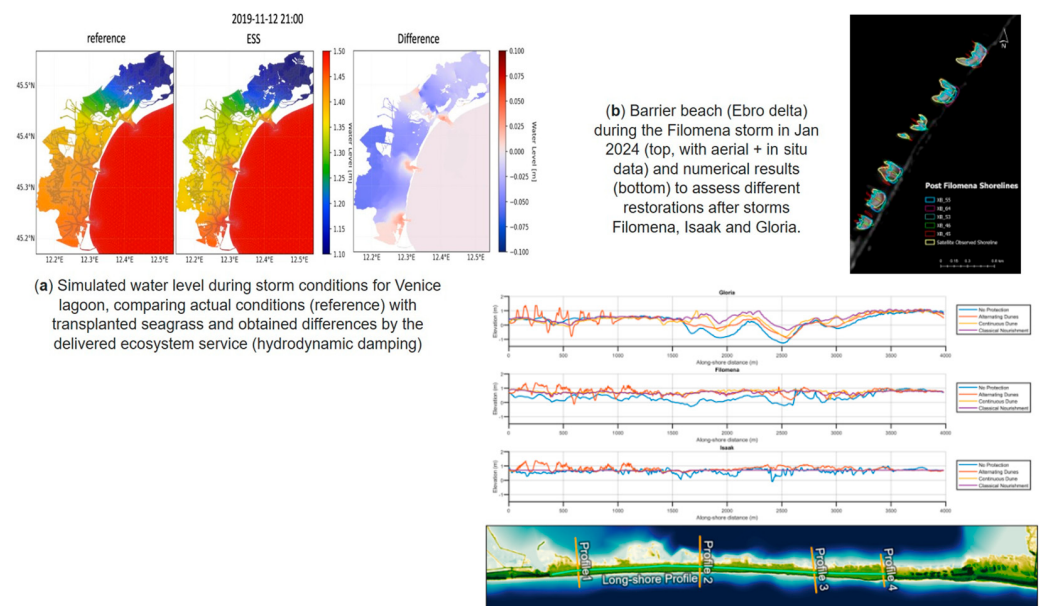


Figure 3. Sample illustration of the predictions produced in the REST-COAST project for two of the restoration pilot cases, both in the Mediterranean Sea: (a) Venice lagoon (left); (b) Ebro delta coast (right), after [13].

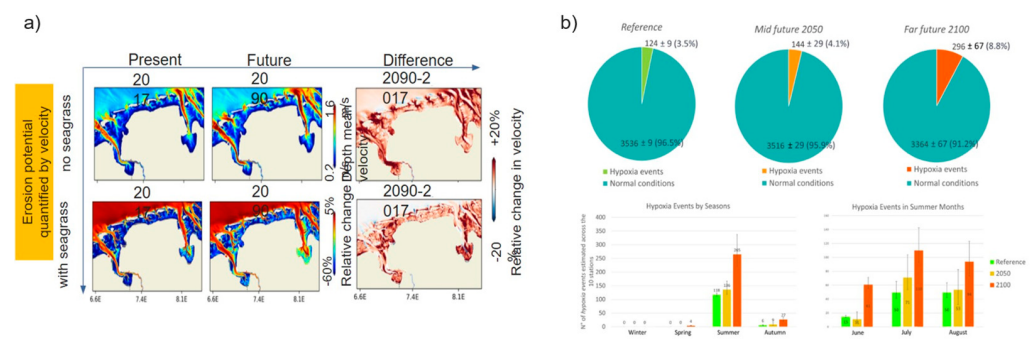


Figure 4. Sample illustration of the projections produced in the REST-COAST project for two of the restoration pilot cases, in the Atlantic and Mediterranean Sea: (a) Wadden Sea protection with seagrass buffer areas; (b) Venice lagoon hypoxia events with seasonal and monthly resolution, with an indicator of error intervals [56].

The proposed systemic restoration must be co-designed by stakeholders from the river–coast continuum, combining technical, economic and governance criteria from various disciplines (biophysical and socioeconomic) across sectors (e.g., irrigation in the river catchment basin and tourism in the coastal zone) and scales (e.g., compatible short-term interventions to reduce coastal erosion with long-term plans to enhance resilience for the wider coastal fringe). To achieve the required convergence of criteria across stakeholders and maintenance across river to sea domains and scales, it is convenient to establish restoration agreements, backed by site-specific restoration platforms, tailored to the local governance structure, and complying with applicable legislation. These restoration platforms and agreements, including technical, financial and governance suggestions for a successful restoration, form the core of this paper. They are acting as enablers that increase the implementation pace and scale of restoration projects in the REST-COAST pilots and should be able to play the same role in worldwide coastal restorations.

4. Ecosystem Restoration Agreements in Different Domains: Experiences and Enablers

Technical, financial, governance, and social barriers have been identified and categorized as frequent impediments to restoration success and upscaling, based on field data and previous analyses [40], as also described in Section 2.3. Co-designed agreements, framed by a common stencil, can be used as an enabler to overcome these barriers because they provide a consensus structure to embed restoration into coastal protection interventions and planning, linking the design, implementation, monitoring and maintenance stages.

This section explores case studies of existing restoration contracts in a variety of ecosystems, examining how they embedded enablers to overcome barriers. The proposed case studies were selected by searching for documented restoration contracts in forest conservation and restoration, wetland restoration, riverine restoration and on-going coastal restoration. The case studies appearing in this section present the clearest documentation on their agreement building process and contents. The outcomes of these case studies are compared and applied to coastal restoration pilots from the REST-COAST project, one of whose main goals is to foster the development and establishment of restoration agreements. The comparison presents how these pilots are implementing similar contracts to circumvent the main barriers for restoration upscaling.

This section explores case studies of existing restoration contracts in a variety of ecosystems, examining how they embedded enablers to overcome barriers. The outcomes of these case studies are compared and applied to coastal restoration pilots from the REST-COAST project aiming to foster systemic and larger scale restoration agreements. The comparison presents how these pilots are implementing similar contracts to circumvent the main barriers for restoration upscaling.

4.1. Privately Owned Forest Conservation Agreements, Germany

Germany was one of the first countries in “western science” to consider conservation. German foresters first coined the term sustainability as a solution to degrading forest conditions, increasing populations and intensifying industry [59]. Today, forest conservation in Germany has been legislated [44], although regulation-enforced conservation has been found to result in a negative financial impact on private foresters, so the German Federal Nature Conservation Act prioritizes voluntary conservation contracts over additional regulation.

The German National Strategy on Biodiversity aims to secure “contract-based nature conservation in 10% of privately owned forest land” [BMU, as cited in [44]]. This study identifies a catalog of private forests where conservation contracts would be suitable, highlighting the barrier that the majority of high-value conservation projects are often already relatively well protected. This leaves threatened forests economically vulnerable, while the effect of conservation on downstream solid transport, which directly affects coastal sustainability, is not normally considered. The focus on local economic valuation and financial barriers in this study is associated with a profit-oriented governance system that does not consider larger-scale implications. Disregarded implications, for instance on the “receiving” coast, as well as broad social and technical implications, are critical to the success of a restoration project.

Of the REST-COAST coastal pilots, Sicily’s Lagoons (Mediterranean Sea) restoration, reflect some of the patterns in Germany’s private forest conservation contracts. Much of this Mediterranean Island’s restoration is funded by the Artenvielfalt Stiftung, a private foundation that funds biodiversity projects. This relationship establishes a financial enabler for the project, where the co-designed restoration includes local organizations like conservation associations, farmers, and tourist operators [60]. Furthermore, the restoration

includes social-ecological interactions, such as mitigating coastal flooding, maintaining biochemical characteristics of the lagoon, and protecting the habitats that support the delivery of ecosystem services. A contract for this type of restoration project should consider the duration of the financial relationship, and it must ensure that relevant aspects related to social, technical, and governance barriers and enablers are included as well.

4.2. Tropical Forest Restoration Through Regenerative Agriculture, Panama

Tropical Forest Restoration has been promoted by the Panamanian Government to meet international commitments, improve water security, and protect biodiversity. In Panama, ranching has turned about 70% of the country's native forests to pastures [61]. This prompted a project to attempt a native species forest restoration in the Azuero Peninsula working with farmers. This project accounts for existing tree planting practices that farmers already engaged in, while planted tree species serve purposes such as fruit harvesting that some of the project's selected native species did not provide [62]. The lack of engagement with local landholders led to the project's limited long-term success, where cultural and social factors play a key role in attribution mechanisms, such as the insufficient involvement of landowners mentioned. Here more data, particularly of a quantitative type, is needed to enable further research on attribution mechanisms, characterizing the response of relevant actors to restoration projects. From the available experience and data, the lack of engagement with local landholders is one key factor limiting the long-term success of restoration interventions, since it hinders the implementation of upscaling plans required to face accelerating climate and human pressures [62]. Large-scale transplantation efforts have been known to fail, especially in agricultural areas, due to landowner resistance [63]. To overcome this barrier, such as for tropical forests, restoration must be bottom-up, using multistakeholder engagement to plan, implement, and evaluate the project benefits. For the Panama case, a new reforestation project in the Azuero Peninsula has begun, working with local landholders and communities to establish agroforestry and silvopastoral model farms to expand regenerative agriculture in the area, while promoting reforestation [28]. These regenerative agriculture systems increase local yields from small areas, enabling a secondary forest regeneration, associated with continued ranching practices, traditional to the area. Such a reforestation approach has served to identify the needs of ranchers, fostering technological, financial, and societal enabling conditions. While this example still lacks the co-design of forest restoration contracts, it highlights the importance of stakeholder engagement to secure the long-term success of a restoration project.

The importance of stakeholder engagement, particularly if included in restoration agreements, can be illustrated by the REST-COAST pilot case in Arcachon Bay, France. A key pressure degrading sea grass meadows in the bay's semi-closed coastal lagoon is oyster farming, an important activity in the local economy [64]. Even though the restoration's initial focus is on repairing the lagoon's hydrological regime, local stakeholders have been involved in the restoration design, compromising on locations where oyster farming may be maintained. This includes the development of regenerative aquaculture sites in the lagoon, where the regional committee for oyster farming could be included as a signing party in the agreement. This would act as an enabler for the long-term success of this restoration, achieving a sustainable compatibility between the future protection of the lagoon ecosystem and historical farming practices.

Another illustration of stakeholder engagement for the compatibility between short-term needs and long-term sustainability can be derived from the REST-COAST pilot in the Ebro Delta, Spain. This case also targets the compatibility between on-going aquaculture practices in the deltaic bays (mussels, oysters, and other bivalves) with coastal morphodynamic evolution and environmental health status. The involvement of stakeholders in the

Restoration Platform aims for sufficient water quality in the coastal bays, as required by aquaculture, by means of a smart co-management of these bays that considers the pressure of longshore sediment transport to close the bay, transforming it into a brackish lagoon [35]. By including bivalve harvesters in the restoration agreement, continued collaborative decision-making can be used to develop long-term regenerative aquaculture, benefiting the bay's ecosystem and enabling the short- to long-term compatibility between aquaculture and the morphodynamic evolution of deltaic bays.

4.3. *The White Mountain Stewardship Contract, USA*

Restoration contracts in the USA, usually termed “Stewardship Contracts”, aim to connect natural resource management to local communities and develop a landscape approach to restoration [65]. The White Mountain case highlights the importance of agreement development, which can be used to build capacity and enable relationships between the various actors involved in restoration. These relations should consider the forest ecological restoration cycle, the local policy planning cycle and the agreement duration periods. Such complex interactions need data with enough temporal and spatial resolution to properly assess restoration evolution and effectiveness during the agreement development, which for this case resulted in a ten-year contract linked to the temporal span of business investment cycles [66]. The time scale is inherently dependent on the spatial domain under restoration, which in this case corresponded to 150,000 acres of federal forests, enacted in 2004 [66].

To set up the agreement, a working group was established ten years before the contract was put in place, bringing together representatives from all relevant sectors to create a collaborative forum. They iterated project changes through each member and worked within the applicable legislation to plan a shared restoration agreement. The working group also built community capacity for restoration practice, which was integral to developing the stewardship contract [66]. The working group still exists as a managing body of White Mountain.

An important outcome of the working group was the establishment of a demonstration site, used to teach a variety of restoration skills which ultimately built social trust and a better understanding of the science behind restoration. It was in these demonstration sites where compromises between social needs, economic needs, and ecological needs were struck. One compromise was limiting the plot diameters of silvicultural treatment, where a flexible mechanism was put in place for these plots to be expanded in the future [66]. The ability of all stakeholders to arrive at a flexible “zone of agreement” was an enabler for the contract signature. It is likely that this zone will be challenged as restoration and climate evolve, needing adjustment and change, where dispute settling mechanisms (e.g., [51]) can be applied as enablers to overcome disagreements.

Such a stewardship agreement with a demonstration site could be applied to any of the REST-COAST pilot restorations and even to future upscaling projects. The flexibility that stewardship agreements provide foster necessary compromise when working with the multiple actors and various governing systems involved in coastal management. Such agreements, supported by the consensus stemming from demonstration site joint work, can also accommodate updates to technical and financing requirements as ecosystems and their services shift. Demonstration sites with this type of agreement may thus provide a robust enabler to overcome restoration technical, financial, social and governance barriers.

4.4. *River Contracts, Italy*

River agreements in Italy tackle the general management of their catchment basins, illustrated by a total of sixty-seven contracts in process, of which twelve were signed already in 2012 [67]. In Italy, the main driver of these agreements are the provinces, although they

may not necessarily be in the implementing body once the contract is in place. The implementation of river contracts follows a specific set of steps: first, a preliminary agreement is signed to work toward a contract; second, a phase of site assessments and knowledge creation is conducted; third, a participatory process agrees on measures delineated in the contract; fourth, a defined action plan is put in place; fifth, the final contract is signed. River Contracts thus act as an enabler for participatory restoration, including its monitoring.

This form of contract could be expanded to river–coast continuums in REST-COAST, particularly the Venice Lagoon pilot in the northern Adriatic Sea. The targeted restoration focuses on river–coast ecosystem connectivity, illustrated for the Venice case by the heavy impact of nutrient and pollutant loads from upstream [68]. Country governance needs to adapt to the proposed restoration agreements, such as is the case of Italy, whose governance structure is already adapted to such river contracts. Furthermore, a wetland contract for the northern Venice lagoon is already in place (“Contratto di area umida per la laguna nord di Venezia”), connecting relevant management actors, and a new governance body has been created to overcome administrative barriers such as differences in the division of responsibilities between basin management agencies, coastal protection agencies and cross-departmental coordination. Building on these advances, the Venice lagoon contract could be expanded to include the river–sea continuum and associated transitional ecosystems, overcoming institutional barriers and providing guidance to implement restoration solutions across formerly disconnected domains.

4.5. Voluntary Wetland Contracts, European Mediterranean

The EU WETNET project (2016–2019) implemented Wetland Contracts to facilitate voluntary stakeholder agreements for the management of protected wetlands [61]. The designation of Ramsar site status often facilitates the development of management plans, but does not lead to relevant stakeholder engagement for site restoration [61]. This type of agreement gathers relevant stakeholders, which should lead to enhanced coordination and monitoring, from which a long-term quantitative assessment of social and ecological benefits can be performed. This assessment should address wetland water and sediment quality, together with the evolution of local populations (e.g., water birds) and biodiversity. The work at the level of the Coastal Restoration Platforms is promoting such data collection and subsequent analyses, to assess restoration performance with time and facilitate the preparation of agreements.

The purpose of WETNET contracts is to build a common strategy for the integrated management of wetlands, coordinating between spatial planning bodies and wetland managers and reducing conflict between economic and conservation targets. The steps of contract development outlined by WETNET can be summarized as follows: first, integrating the knowledge of each stakeholder; second, clarifying restoration goals and concerns; and third, agreeing on a site-specific contract. An important enabler has been the role of an international body, like WETNET, to foster a collaboration base across different countries [69]. Wetland contracts have been accepted as a tool for all Ramsar sites, but contracts have mainly been adopted in countries where initiatives like WETNET took place. This indicates the need to improve supportive governance, as an enabler to the implementation of restoration agreements, adaptable to the context where they are implemented.

In the Mediterranean, managers of Marine Protected Areas (MPA) are challenged by the lack of long-term restoration contracts [6]. This has led to financial and technical barriers like funding, staffing, data, and equipment constraints. While legislation like the 2024 European NRL can alleviate some of these constraints, the management of available funds, as well as the collaboration between MPA managers, could profit from agreements like the one here proposed. Such agreements could secure technical enablers by establishing periodic

restoration trainings, communication between MPA managers, and improved baselining methods—and similarly, for the financial and governance dimensions in the agreements.

5. Coastal Restoration Agreements: Experiences and Enablers in the REST-COAST Pilot Cases

The REST-COAST pilots are a first step in upscaling coastal restoration to achieve shared benefits such as coastal protection, ecosystem conservation, and livelihood preservation. Governance, economic, social, and technical barriers and enablers have been identified in previous works (i.e., [40]) and reinforced in the context of coastal ecosystems [11], where the developed enablers should be applied to overcome restoration barriers at short- to long-term scales. Applied active and passive techniques, supported by observations and simulations, have led to improved funding and social engagement, based on the quantified restoration co-benefits. These demonstrated benefits should, in turn, promote a governance shift to overcome present fragmentation and limited long-term plans for coastal restoration, thereby reducing the current implementation gap. This section will discuss how two REST-COAST pilots are using restoration agreements as a tool to leverage enablers against current barriers, which hamper the adaptation potential of the analyzed coastal systems. The remaining REST-COAST pilots have already also produced the basis for such contracts, which are at different levels of development and always discussed within the Coastal Restoration Platforms established at each of the nine study sites.

5.1. Declaration of Intent for a Growing Coast, the Netherlands

The Wadden Sea pilot case in REST-COAST provides an excellent example on how to tackle cross-border restoration, where here the focus is on the restoration of the Ems Estuary near Groningen (Figure 5). This estuary faces a variety of pressures, including sea-level rise, which have placed the surrounding intertidal ecosystems at risk [15]. Furthermore, navigation pathways and land reclamation have increased water turbidity and influenced tidal dynamics, under the need to dredge surplus sediments. The major risks addressed by the estuarine restoration stem from flooding, erosion and coastal habitat loss, quantitatively assessed from combined observations and simulations (Figure 6).

This pilot case opted to use a legal contract as the restoration agreement, signed for a ten-year period, with a part of the agreement extending twenty-five years into the future. These long-term restoration agreements should address the potential impact of sediment pollutants and the disturbance produced by sediment removal on the estuarine water turbidity and water/sediment quality. Any restoration implementation complies with Dutch and European legislation, including the pertinent environmental risk assessments, which consider the potential impact of sediment pollutant content (such as heavy metals and persistent organic matter). This is a common problem when restoring connectivity, since sediment deposits in reservoirs or estuarine beds can contain pollutants that affect soil quality in farmland or water quality in all involved habitats. The disturbance produced by sediment removal and dumping can also affect the balance of estuarine and coastal ecosystems, which is included in the environmental risk assessments. The proposed restoration agreements facilitate stakeholder collaboration for the consensus analyses of these impacts and any possible mitigation measures required, which promotes long-term sustainability and maintenance.

The proposed contract is divided into five main articles that outline (a) main actors affected by the restoration; (b) goals of the restoration contract; (c) measures through which these goals will be accomplished; (d) interests of the participating actors; and (e) main intents of the contract. The contract is signed by eight actors, identified in the first article, where the first three are the Province of Groningen, the Emsdelta Municipality, and the

Oldambt Municipality. These are the governing bodies tied to the estuary and that set the governance regime. The fourth actor is a local water authority that affects and is affected by the water quality of the estuary. The port authority is included for its role in planning and improving dredging projects. The contract has also involved a regional farming association because sea-level rise and the estuary's soil subsidence put surrounding agricultural fields at risk. Finally, there are two actors that advocate for ecosystem integrity in Groningen, the Groningen Landscape Foundation, and an alliance of climate and nature organizations.

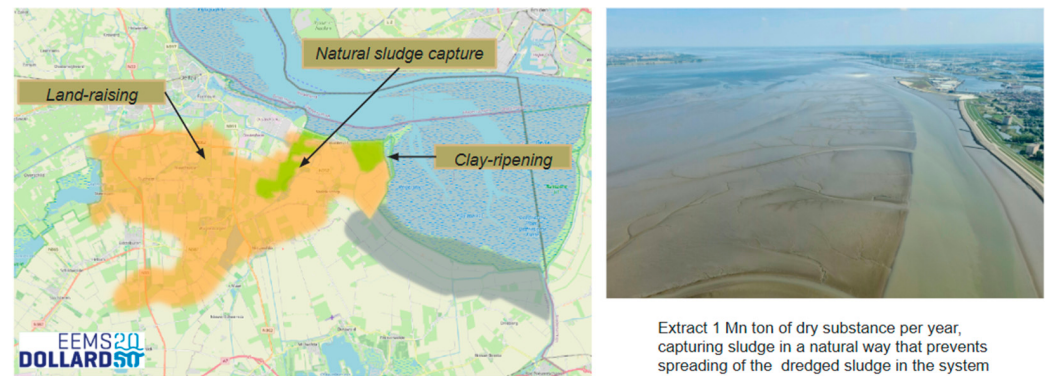


Figure 5. Restoration of the Wadden Sea and Ems estuary, implementing the portfolio of co-designed NbS solutions, where researchers and stakeholders from the REST-COAST coastal restoration platform participate.

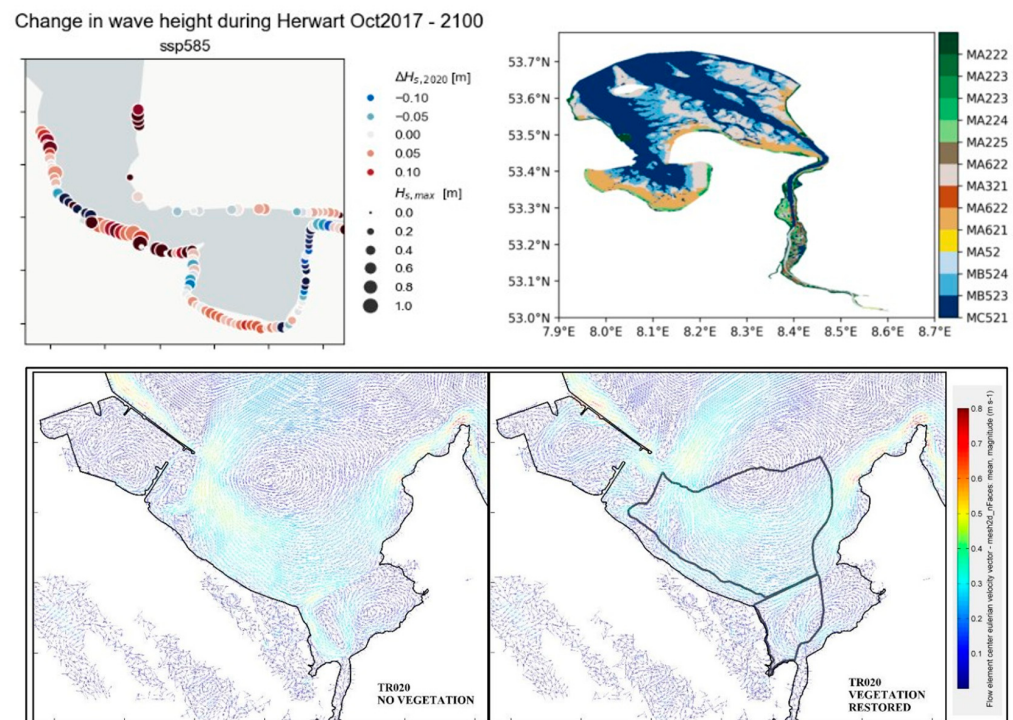


Figure 6. Sample simulations for reduction in H_s (significant wave height) along the Ems estuary boundary considering SLR and restoration (top left); projected habitats for the Wadden Sea (top right) by 2090; reduction in flow velocities over present (bottom left); restored seagrass areas for a 20-year return period event of moderate energy (bottom right).

Article 4 outlines each party's interests and what they expect to gain from the proposed restoration, which can be used as a basis for compromise and conflict-solving. Articles 1 and 4 embed social enablers into the contract by developing sufficient communication and agreement mechanisms between all relevant actors. Article 2 outlines the scope

of the contract and what the actors are aiming to achieve by signing it. This article also defines the broader policy goals that will be met by accomplishing the restoration project. These goals are made concrete in Article 3 by defining the main quantifiable actions. Two of these actions address the beneficial use of dredged sediment to (1) raise 300–500 ha of agricultural land safely above sea level and (2) use 2 million cubic meters of clay from the dredged sediment to renovate the Dollard dike. The third restoration measure is to create inland and tidal habitats that promote sedimentation, reduce erosion and enhance vertical accretion. A fourth restoration measure concerns the long-term integration of restoration efforts into the desired surrounding landscape evolution. This section embeds technical enablers into the contract by identifying the key biophysical adjustments that must be made to the ecosystem. Article 2, together with Articles 1 and 4, tackle governance enablers by ensuring that relevant governing bodies are included in the contract and that their policy goals are addressed by the restoration.

Article 5 outlines the next steps that must happen to efficiently implement the co-selected measures and achieve the contract goals. An important section of this article is the description of funding arrangements, identifying existing funding commitments and proposing additional funding as enablers to enhance restoration implementation. Article 5 also highlights the main expected barriers, such as organizational challenges, identifying future steps to overcome them. A similar method is taken to reduce technical barriers, stating the main requirements for ecological plans, together with their monitoring and evaluation for controlled adjustments. Article 5 plays a pivotal role in the contract, addressing potential governance, social, financial, and technical barriers. Moreover, it introduces a mechanism for adaptability, thereby facilitating future challenges to be reframed and leveraged as enablers.

5.2. Agreement on Cooperation for the Vistula Lagoon, Poland

The Vistula Lagoon in Poland is a Natura 2000 site with thirteen endangered migratory bird species that rely on the ecosystem the lagoon provides. The lagoon faced a planned shock in 2020 when a passage to the Baltic Sea was opened on the Polish side of the lagoon [70]. To compensate for essential habitats lost in the passage construction, a Vistula Lagoon restoration plan was launched, which included building an artificial island in the lagoon (Figure 7) that can support endangered bird species and lead to biodiversity gains.

The restoration agreement for this lagoon pilot was comparatively simpler to establish, because there are fewer actors involved and, therefore, the existing governance was better suited for the implementation of restoration interventions. The governance structure enabled the implementation of more integrated decisions, all of them coordinated by the Maritime Office, with full responsibility for this task. Thus, the agreement made between the Polish Maritime Office and the Academy of Sciences' Institute of Hydro-Engineering has acted as an enabler to start filling the implementation gap for all restoration activities, coordinating the planning, implementation and monitoring stages of the deployment.

The agreement outlines the roles and responsibilities of the two signing actors, which refer to the following: (a) restoration aims; (b) restoration responsibilities; and (c) supporting cooperation agreements. The document also refers to the technical enablers required, conditioning the building methodology to the soil-bearing capacity and the constructed ecosystems to the local climate (Figure 7), all framed by the available space on the artificial island. Furthermore, there is a clause in the contract that establishes a formal pathway for alterations or renewals of the agreement, depending on the evolution of boundary conditions. This is a provision for flexibility that could be used to resolve future conflicts and is thus an enabler that should be of application in many other restoration contracts.

Ultimately, this document is used to formalize the relationship between the governing body and the research institute, securing an efficient governance enabler.

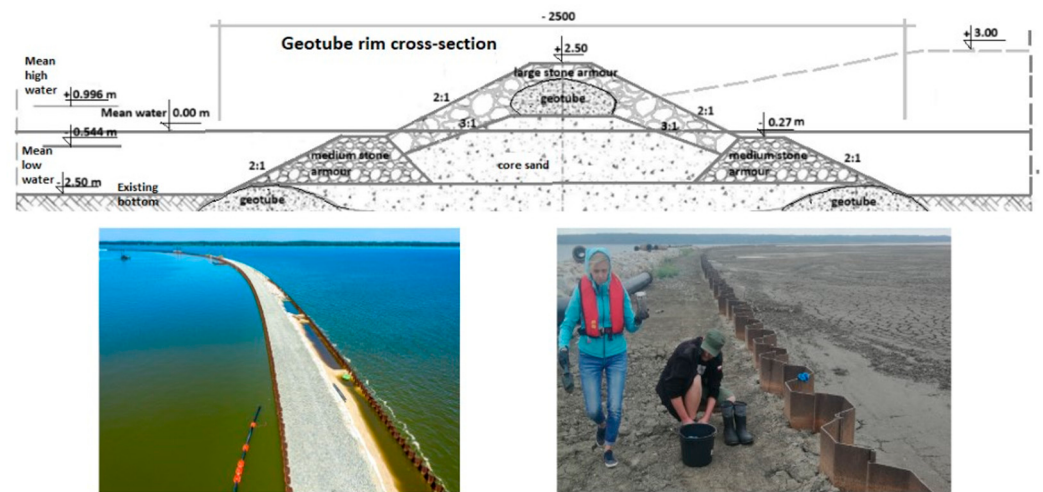


Figure 7. Constructed island for habitat compensation and biodiversity gains in the Vistula lagoon, where the initial design was based on a geotube-based rim (**top**) that became too unreliable due to high and uneven subsidence risk and had to be replaced by Larsen sheet piles, with two rows of 13 m-long units forming a 1192×1932 ellipse (**bottom left**) whose soil properties such as level, moisture or organic matter (**bottom right**) are being regularly monitored.

5.3. Limitations on Case Transferability

The agreements established by Dutch and Polish REST-COAST pilots illustrate how place-based constraints lead to differences in how agreements are designed and implemented. The Vistula Lagoon in Poland is already an area of conservation status with a clear top-down governance structure. This means that the agreement development process was streamlined and put pre-defined roles in the context of a restoration-oriented project, which also aims to conserve values and promote benefits for people and nature. The Wadden Sea agreement in the Netherlands benefited from a more flexible contract creation, because it developed new relationships between national, public, and private actors. The same agreement could not be applied to both case studies, since local factors strongly condition the text of the agreement, which should be based on consensus and engagement by all local actors. In addition, the factors that condition the agreement text, related to techniques, governance, funding and engagement, may vary in future restoration agreements, where new financing instruments, such as land ownership and willingness to participate, are to be expected. These agreements should remain legal and enforceable, which requires regular updating such as is being discussed in the Coastal Restoration Platforms established at each of the sites.

These nine pilots, representing hotspots of coastal vulnerability under climate change, feature different biophysical conditions and socioeconomic settings, key to export the approach to other coastal sites worldwide. The selected pilots are representative of coastal conditions on European coastlines and cover Baltic, Black, Mediterranean and North Sea coasts, as well as the Bay of Biscay for the Atlantic coast. The pilots include deltas (e.g., Ebro and Rhone), estuaries (e.g., Waddensee), and lagoons (e.g., Venice and Vistula) and feature different levels of governance aggregation and social engagement, sweeping a large enough set of social-ecological conditions to facilitate deriving exportable criteria and metrics [11].

Restoration agreements are being used to strengthen existing governance structures and to fill governance gaps, always complying with local biophysical conditions and socioeconomic criteria. In spite of the local variability found, all agreements present a similar structure, which is the basis for exporting an adjustable template for future

restoration projects in new locations. The proposed structure has facilitated the co-selection of present and target status for the considered coastal systems, leading to an enhanced consensus on the restoration measures and their implementation.

6. Coastal Restoration Platforms: Living Labs to Steer Adaptation Evolution

The set of restoration agreements, either signed or at different levels of development, share a common structure, co-designed by all stakeholders participating in the nine ongoing coastal restoration platforms (COREPLAT) at the nine pilot sites in the REST-COAST project. The agreements' contents can be grouped in ten blocks: (a) restoration aims, defining the present and future (target) states; (b) participating stakeholders, describing their roles and legally established competences; (c) adaptation-through-restoration plans, which delineate adaptation pathways with tipping points and consensus sequence of restoration interventions; (d) co-selected metrics to assess coastal risk evolution under changing climate and human pressures, establishing an objective ranking for restoration success; (e) portfolio of co-designed solutions at preliminary design level, including initial and maintenance costs, estimated delivery of ecosystem services and main expected impacts; (f) business models and plans detailing the required funding (mainly public sector) and financing (private investors or joint public–private ventures), based on the monetization of ecosystem services and the initial/maintenance costs; (g) co-selected thresholds to activate initial (yellow warning) and urgent (red warning) interventions to curb increasing risks for natural and socioeconomic assets in the most vulnerable coastal sectors; (h) monitoring and associated maintenance plans, incorporating if available early warning systems (EWS) for short-term decisions and climate warning systems (CWS) for long-term decisions; (i) recommendations for a more integrated and proactive governance, together with suggestions for more supportive policies for restoration upscaling; (j) co-designed recommendations to increase the pace and scale of restoration, overcoming site-specific barriers (as found in the project pilot cases); and (k) co-defined adaptation pathways to establish tipping points and sequence the proposed interventions based on shared key performance indicators to assess restoration performance and potential for upscaling. These restoration agreements, developing the sequenced application of interventions that combine technical, economic and governance advances, share a common structure supplemented by pilot-specific clauses. Such a common structure contains the following headings: (a) coastal risk reduction under evolving climate and human pressures; (b) target socioeconomic and environmental status; (c) portfolio of interventions to enhance resilience and limit negative impacts; (d) adaptation plan for compatible short- to long-term interventions; (e) climatic justice plan for an ethical use of scarce natural resources such as accommodation space [71] or freshwater volume; and (f) circular economy plan to enhance the restoration financial sustainability under a limited coastal carrying capacity. These chapters are tailored to the specific needs of each study case, as set out by each COREPLAT, a co-management table that regularly assembles all key stakeholders to monitor, evaluate and maintain restoration by consensus agreements and joint work. The COREPLATs aim to accelerate the scale and pace for co-designed interventions, supported by engineering and financial provisioning to make restoration commensurate with climatic acceleration. These platforms, structured as living labs, integrate the needs and criteria of participating stakeholders, which include public ones (coastal protection, land planning or river regulation administrations), NGOs (supporting conservation principles), citizen groups (dealing with scarce resources), biodiversity organizations and private groups (tackling risks or finance).

The COREPLATs running in all pilot sites promote adaptation-through-restoration plans, which favor restoration for degraded coastal environments to achieve an adaptation that is effective and that reduces the carbon footprint of traditional coastal protection. These

plans, supported by the technical, financial and governance advances achieved [11,53,72], are framed within adaptation pathways and steered by consensus metrics. Consensus metrics enable a regular assessment of implementation effectiveness and maintenance needs to enhance the delivery of short- to long-term ecosystem services. These metrics refer to key variables for biophysical drivers (e.g., temperature, wave energy, sea level, pollutant/nutrient concentrations), responses (e.g., erosion rates, flood extent/duration, water quality, biodiversity status or aquaculture production) and socioeconomic impacts (e.g., risk levels, investment needs, revenue generation). Restoration plans, supported by these metrics, are being deployed in time and space according to the co-selected adaptation pathways, with consensus change stations and tipping points, informed by regular assessments of the implemented interventions in terms of impact, cost and effectiveness. The proposed interventions, illustrated for the Ebro river–coast pilot case (Figure 8) by controlled river pulses, enhanced coastal roughness and natural conveyor belts for coastal sand fluxes [11], have the overarching aim of reconnecting rivers to coasts and people to nature.

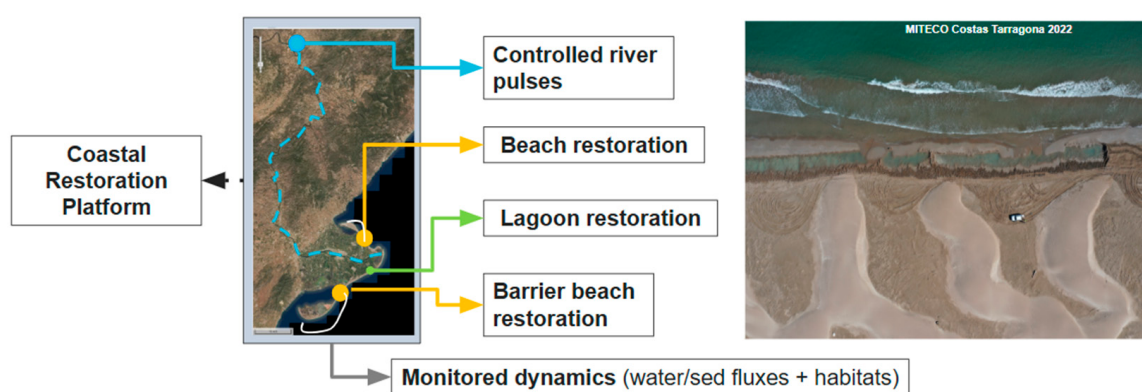


Figure 8. Systemic restoration plans, deployed across the river–delta–coast continuum according to co-selected adaptation pathways with consensus tipping points for the Ebro river–coast system in the Spanish Mediterranean coast. The adaptation-through-restoration plans combine recovered river–coast connectivity and natural coastal dynamics based on enhanced coastal roughness, maintained through a systemic monitoring plan that spans river, coastal, and sea domains.

For this case, municipalities from the catchment basin have become aware that sharing sediment and freshwater with downstream communities will be beneficial for both upstream and downstream socioeconomic conditions, providing shared ecosystem services such as common water quality or beach uses for upstream visitors. By using such a systemic approach, openly discussed within the COREPLATs, the municipalities from the northern and southern regions of the delta, for instance, have become aware that the prevailing water and sediment scarcity requires reaching a compromise, prioritizing coastal or river stretches that have suffered more during recent stormy seasons. It makes sense to dedicate scarce natural resources to restore the sites most affected, which will result in shared benefits for all communities. This approach should be based on cooperative agreements to share these scarce resources and to implement a systemic restoration, where municipal actors become aware of the need to share scarce natural resources whose deficit is expected to increase under climate change. This is key for socioeconomic engagement since municipal managers and coastal communities are the first line to experience climatic pressures. The combination of adaptation-through-restoration plans with the open communication within the COREPLATs have empowered municipalities to become aware of the co-benefits from controlled river pulses to enable coastal zone sediment fluxes. Furthermore, this systemic

approach emphasizes the need to share limited resources (i.e., sediment, freshwater) to protect the most vulnerable locations and to reduce overall risks.

The portfolio of co-selected restoration interventions, prepared at draft-project level but with costs and impacts, should be sequenced along the co-designed adaptation pathways, with deadlines and implementation warnings displayed along the horizontal time axis (Figure 9). Along these pathways may appear tipping points, for instance because of erosion and flooding, when there is not enough “coastal room” to deploy embryonic dunes. This indicates a limit for an adaptation pathway based on “coastal roughness”, an ecosystem service delivered by the embryonic dunes. This applies to both the Northern (la Marquesa beach) and Southern (Trabucador beach) coastal sectors considered in the analysis. At Trabucador beach, the extreme sediment deficit can cause the emerged barrier beach to breach and become submerged, which means that to ensure the full delivery of ecosystem services by embryonic dunes, enough beach width should be provided. The tipping point occurs when there is not enough space anymore, and here “enablers” to avoid crossing the tipping point should be introduced.

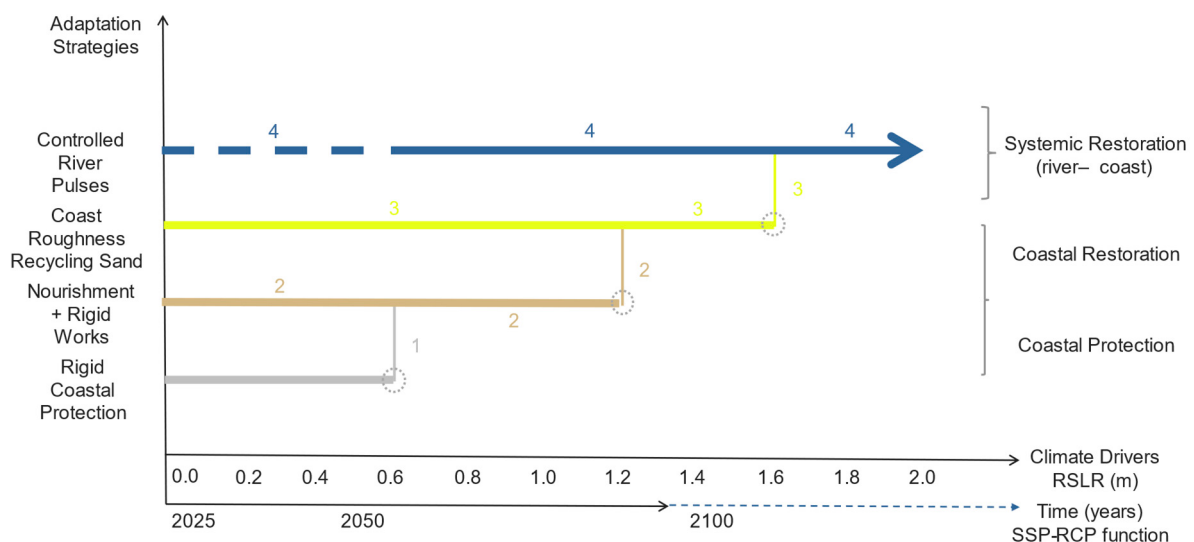


Figure 9. Set of co-designed adaptation strategies for the Ebro Pilot, illustrating vulnerable river-coast deltaic systems in the Mediterranean Sea. Sequenced interventions are to be deployed along adaptation pathways, as a function of relative SLR or the combination of climatic drivers considered, where dashed lines indicate pathways not yet implemented or with uncertain limits, and dashed gray circles denote change stations, warning that tipping points are getting closer. These climatic drivers are then translated into time depending on the family of co-selected scenarios (horizontal axis).

These tipping points, which indicate when the next intervention must be put in place to enhance coastal resiliency, can also be illustrated by the point when there is not enough compatible sand to restore embryonic dunes and coastal beach roughness. When this is the case, adaptation can be improved through controlled river pulses, until there is not enough fresh water left (the final tipping point). The proposed portfolio of interventions includes (a) monitoring to assess beach width and berm level elevation; (b) additional shoreface and berm artificial nourishment; (c) construction of submerged sand bars mimicking breaker bars that act like submerged breakwaters; (d) enhanced vegetation in the emerged and submerged beach sectors to damp hydro-morphodynamic fluxes; and (e) managed realignment considering backbeach features. Without regular monitoring and renourishment to maintain these nature-based solutions, the municipal actor will not easily accept coastal protection based on ecosystem services, reverting to the

traditional rigid works that have been in use for the past centuries with results that are projected to worsen under climate change.

The proposed interventions should be implemented and maintained according to the predictions and projections provided by the EWS and CWS available in some pilot cases, which should also support the engineering required for the delivery of targeted ecosystem services [11]. EWS refer to the short-term (scale of about 7 days, for which predictions are available), where municipal actors, based on short-term predictions, can know 7 days in advance where and when the barrier beach will be breached. Therefore, they can take proactive measures to reinforce the most vulnerable sections of the barrier beach before the storm begins (Figure 10a). CWS refer to the long-term (scale of several decades for which projections are available). Municipal actors can use the climate warning system to plan land-uses, for instance to promote the creation of coastal room, a consensual retreat or even a land reclamation, aiming to preserve the minimum beach width that enables maintaining important ESS, such as reduction in erosion and flooding risks. These simulations, nested within Copernicus products which provide high-resolution boundary data for European coasts, should progressively incorporate the error intervals derived from field observations (Figure 10) [11].

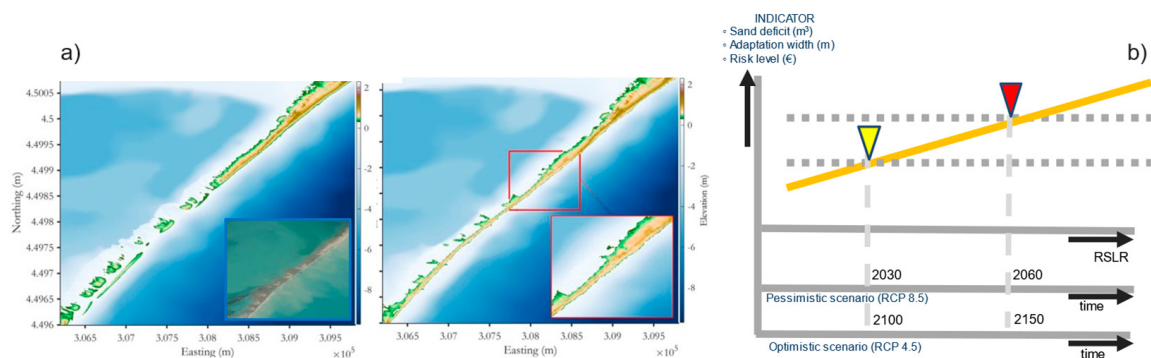


Figure 10. Sample results from the EWS and CWS for proactive adaptation decisions in the Ebro delta (Mediterranean Sea) at short- to long-time scales: (a) EWS at a barrier beach, showing breaching without embryonic dunes (left) and resilience by embryonic dunes (right); (b) CWS built with RSLR as a basic independent variable (horizontal axis), translated into time depending on the selected scenarios, and a vertical axis for the evolution of the risk/resilience indicator selected (sand deficit, beach width deficit and risk).

Adaptation-through-restoration plans must also address the provisioning of funds by public and private means, including business plans for enhanced investment and recommendations to increase and accelerate the contributions by administrations (e.g., enabled land areas, ecological permits, timely impact assessments) and other social actors. Distributed funding, supported by blockchain-based certificates, has been explored in a number of sectors, since it provides a transparent and efficient certification system. This funding, already applied in forest restoration and cultural heritage [73,74] has also been promoted by finance companies, such as the Priceless Planet Coalition by Mastercard, which in 2024 expanded its portfolio of restoration sites [75]. Following this evolution, joint public–private ventures and private investments, including those supported by blockchain electronic ledgers, the restoration pace can be increased based on growing consensus and co-responsibility.

Moreover, co-designed adaptation pathways offer a structured solution to increase funding and supportive governance for upscaled restoration, filling the current implementation gap and adaptation deficit that coasts are facing. The business plans proposed for the REST-COAST pilots contribute to increase and make more specific the social-ecological

shared benefits from restoration, setting out the newly generated revenue streams from delivered ecosystem services [76]. These achievements can be demonstrated by making more explicit the enhanced delivery of ecosystem services and co-benefits for all investors, associated with a proactive implementation and maintenance of restoration interventions. Such plans, supported by socioeconomic engagement and consensus derived from the COREPLATs, should be monitored and maintained by applying the developed EWS and CWS, which enable to sequence and prioritize the co-selected solutions within a plan for upscaling restoration (Figure 11).



Figure 11. Illustrations from the plan to upscale coastal restoration in the northern part of the northern Ebro delta coast (**left**, **right** inset), within the red line domain (**left** inset). The picture also shows the proposed combination of active and passive restoration, combining enhanced coastal roughness (embryonic dunes) with the deconstruction of artificial barriers for coastal “room” (**right**).

Continuous monitoring for maintenance is thus a key element of these plans, where new data register the performance of restoration interventions and delivered co-benefits, regularly discussed within the COREPLATs to increase socioeconomic engagement through improved perception and awareness. The resulting engagement supports the shift in governance required for restoration upscaling, supported by the advances in technical practice, financial mechanisms and governance shift embedded in the developed adaptation-through-restoration plans (Figure 12).



Figure 12. Some of the nature-based-solutions building blocks for the upscaled restoration plans in a set of lagoons in the Sicily pilot case (**left**), combining seagrass reconstruction (**left**), marsh restoration (**top right**), bird island building (**bottom left**) and hydraulic connectivity management (**bottom right**). Such systems, restored with the proposed upscaling (red line domain) for adaptation-through-restoration plans, provide gains in biodiversity and systemic risk reduction, enhancing natural and socioeconomic resilience under climate change.

7. Discussion and Conclusions: Restoration Sustainability

Coastal restoration agreements, supported by restoration platforms like the CORE-PLATs established within the REST-COAST project, can act as enablers to overcome the multiple barriers that hinder a wider restoration uptake. By embedding governance, financial, social, and technical enablers directly into the contractual text, these agreements foster an informed collaboration, secure long-term funding, and ensure an adaptive management that leads to restoration upscaling. Table 1 presents a summary of key performance indicators that are being used in the REST-COAST project to assess restoration performance and implementation, applying the developed enablers to promote large-scale restoration implementation. Such upscaling is key for a sustained delivery of ecosystem services [11] that effectively curb coastal risks under the projected climate change acceleration.

Table 1. Compiled information on restoration impacts, enablers, barriers, and KPIs from the pilot cases in the REST-COAST project. # stands for number of achievements in the KPI accounting.

Impact	Enabler	Barrier	KPI	Target
Accelerated evolution of coastal zone governance/policies	New governance/policy for ecosystem services and biodiversity	Fragmentation and short-term views	# coastal zones with new governance/policies	≥ 7
Increase engagement for restoration	Cross-sector/long-term restoration	Social memory and institutional inertia	# registrations in COREPLATs	≥ 200
Continued or increased restoration funding	Grants, carbon or resilience bonds	Economic crises/NBS confidence	# new co-funding tools and applications	≥ 10
Restoration upscaling and project integration	Enhanced river–coast connectivity	Governance and biased interests	# integrated restorations	≥ 10
Carbon footprint and storage	Decarbonized adaptation via ecosystem services	Lack of space for accommodation	# low-carbon coastal zone adaptation projects	≥ 10
Risk reduction for people and environment	EWS and CWS with and without restoration	Small-scale and short-term views	# warning systems with or without ecosystem services	≥ 5

The enablers developed to overcome barriers in the different pilots can be illustrated by (a) new techniques for restoration (e.g., biomimetic devices or embryo dunes with wrack cores); (b) new management based on proactive interventions and maintenance (e.g., deadlines for interventions derived from monitoring and the warning systems); (c) enhanced funding and financing (e.g., co-designed business plans with public–private joint ventures); (d) flexible adaptation-through-restoration plans that combine NbS building blocks (e.g., river–coast connectivity or constructed coastal roughness); (e) governance transformation with more integration for systemic assessments (e.g., low carbon protection and coastal blue Carbon in Nationally Determined Contributions); and (f) new policies for coastal restoration based on effectiveness and risk reduction complying with new legislation (e.g., NRL [39], relevant EU Directives, US landscape approach restoration or Australian land-based covenants [77]). As the nine pilots complete their interventions and begin collecting data on their monitoring and metrics, future research should quantitatively analyze how the indicators (e.g., Table 1) assess barrier effects, restoration effectiveness and the role of enablers in coastal restoration.

Barriers to interventions stem from a variety of factors related to techniques, funding, governance and social engagement, whose role varies from site to site and with time during the restoration implementation. The different levels of data available in the pilots have precluded any statistically robust regression analysis, which remains a clear need

for on-going restoration research. The newly collected data show that the most constraining barrier is fragmented and short-term governance, followed by the limited technical expertise on upscaling restoration, the lack of universally accepted metrics, and finally, the transient character of available funding. The enablers proposed to overcome those barriers are related to consensual management, systemic monitoring and modeling, co-selected metrics that encompass all relevant social-ecological key variables and longer-term funding plans. All these enablers are being considered in the Coastal Restoration Platforms, keeping all stakeholders duly informed about the potential and limits of the analyses and tools prepared.

This is key for robust decision-making and prioritizing interventions, since only quantitative analyses can provide long-lasting links between grassroots criteria and overarching management goals. Unfortunately, this level of quantitative analysis, applied to a sufficient number of restoration pilots for extrapolation, is not yet available either in the pilots here considered or in the restoration database prepared during this project. Such a quantitative and statistically based comparison should pave the way to upscale restoration projects in the nine pilots considered and elsewhere, supported by regular monitoring and advances in multi-dimensional metrics for restoration performance, which should lead to regular updates of key performance indicators (e.g., Table 1) and the effectiveness of enablers to overcome barriers to upscaling plans. The proposed restoration agreements, tailored to dominant social-ecological features for each of the REST-COAST pilot cases, address local challenges and incorporate place-based criteria, aligning relevant stakeholders with shared restoration goals. These agreements serve not only as a tool for overcoming specific barriers but also as instruments of opportunity, ensuring that restoration upscaling can evolve alongside changing ecological, social and economic contexts. The lessons learned from contracts developed for forests, rivers, wetlands and other coastal systems, together with the expertise gained in restoration agreements and platforms within REST-COAST, offer valuable insights for upscaling restoration to worldwide coasts to increase preparedness for a global climate change. By applying restoration indicators and the innovative advances in techniques, funding and governance, it should be easier to export the gains in environmental health and socioeconomic livelihood to many vulnerable coastal systems, advancing towards standardized criteria for restoration performance. The proposed contractual approach, supported by platforms organized as living labs for the REST-COAST pilot cases [11], can steer an efficient restoration upscaling to fill the present implementation deficit, promoting the use of the obtained enablers (referred to techniques, financing and governance) for proactive coastal restoration worldwide.

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Abbreviations

The following abbreviations are used in this manuscript:

BMU	Bundesministerium für Umwelt, Naturschutz, und Reaktorsicherheit
COREPLAT	Coastal Restoration Platform
CWS	Climate Warning System
ER	Ecological Restoration
EU	European Union
EWS	Early Warning System
GDF	Global Biodiversity Framework
KPI	Key Performance Indicator
MPA	Marine Protected Area
NbS	Nature-based Solution
NGO	Non-governmental Organization
NRL	Nature Restoration law
REST-COAST	Large-Scale Restoration of Coastal Ecosystems through Rivers to Sea Connectivity
SAC	Special Area of Conservation
SLR	Sea-level Rise
SPA	Special Protected Area
WETNET	Coordinated Management and Networking of Mediterranean Wetlands Project

References

1. Mentaschi, L.; Vousdoukas, M.I.; Pekel, J.-F.; Voukouvalas, E.; Feyen, L. Global long-term observations of coastal erosion and accretion. *Sci. Rep.* **2018**, *8*, 12876. [CrossRef]
2. Pernice, U.; Coccon, F.; Horneman, F.; Dabalà, C.; Torresan, S.; Puertolas, L. Co-developing business plans for upscaled coastal nature-based solutions restoration: An application to the Venice Lagoon (Italy). *Sustainability* **2024**, *16*, 8835. [CrossRef]
3. Sánchez-Arcilla, A.; García-León, M.; Gracia, V.; Devoy, R.; Stanica, A.; Gault, J. Managing coastal environments under climate change: Pathways to adaptation. *Sci. Total Environ.* **2016**, *572*, 1336–1352. [CrossRef]
4. Sánchez-Artús, X.; Gracia, V.; Espino, M.; Grifoll, M.; Simarro, G.; Guillén, J.; González, M.; Sánchez-Arcilla, A. Operational hydrodynamic service as a tool for coastal flood assessment. *Ocean Sci.* **2025**, *21*, 749–766. [CrossRef]
5. Schuerch, M.; Kiesel, J.; Boutron, O.; Guelmami, A.; Wolff, C.; Cramer, W.; Caiola, N.; Ibáñez, C.; Vafeidis, A.T. Large-scale loss of Mediterranean coastal marshes under rising sea levels by 2100. *Commun. Earth Environ.* **2025**, *6*, 128. [CrossRef]
6. Spalding, M.D.; Ruffo, S.; Lacambra, C.; Meliane, I.; Hale, L.Z.; Shepard, C.C.; Beck, M.W. The role of ecosystems in coastal protection: Adapting to climate change and coastal hazards. *Ocean Coast. Manag.* **2014**, *90*, 50–57. [CrossRef]
7. Tanner, M.; Puig Marti, P. Inventory Report on Restoration Needs, Competencies, and Capacity Building in Mediterranean MPAs. MedPAN. Funded by the EU RESTO-COAST Project. 2025. Available online: https://medpan.org/sites/default/files/media/downloads/inventory_report_on_restoration_needs.docx.pdf (accessed on 25 October 2025).
8. Wu, W.; Biber, P.; Bethel, M. Thresholds of sea-level rise rate and sea-level rise acceleration rate in a vulnerable coastal wetland. *Ecol. Evol.* **2017**, *7*, 10890–10903. [CrossRef] [PubMed]
9. Arkema, K.K.; Guannel, G.; Verutes, G.; Wood, S.A.; Guerry, A.; Ruckelshaus, M.; Kareiva, P.; Lacayo, M.; Silver, J.M. Coastal habitats shield people and property from sea-level rise and storms. *Nat. Clim. Change* **2013**, *3*, 913–918. [CrossRef]
10. Gracia, A.; Rangel-Buitrago, N.; Oakley, J.A.; Williams, A.T. Use of ecosystems in coastal erosion management. *Ocean Coast. Manag.* **2018**, *156*, 277–289. [CrossRef]

11. Sánchez-Arcilla, A.; Garrote, L.; Gracia, V.; Cáceres, I.; Sánchez-Artús, X.; Caiola, N.; Espanya, A.; Espino, M.; García, M.Á.; Grassa, J.M.; et al. Trade-offs and synergies in river-coastal restoration for the Ebro case (Spanish Mediterranean). *Nat. Conserv.* **2025**, *59*, 101–137. [\[CrossRef\]](#)
12. Van Coppenolle, R.; Temmerman, S. Identifying global hotspots where coastal wetland conservation can contribute to nature-based mitigation of coastal flood risks. *Glob. Planet. Change* **2020**, *187*, 103125. [\[CrossRef\]](#)
13. Sánchez-Artús, X.; Subbiah, B.; Gracia, V.; Espino, M.; Grifoll, M.; Espanya, A.; Sánchez-Arcilla, A. Evaluating barrier beach protection with numerical modelling. A practical case. *Coast. Eng.* **2024**, *191*, 104522. [\[CrossRef\]](#)
14. Marín, P.A.; Arroyo, A.; Costa, G. EU Nature Restoration Regulation and REST-COAST: Setting the Basis for Coastal Restoration (Grand Agreement No. 101037097; Deliverable D5.5.). EU Horizon 2020 REST-COAST Project. 2024. Available online: <https://rest-coast.eu/storage/app/uploads/public/674/583/097/674583097d9ea720789462.pdf#Policy%20Brief> (accessed on 25 October 2025).
15. Wanke, S.; Baptist, M.; Jacob, B. Wadden Sea/Ems Dollard Pilot Fact Sheet. 2022. Available online: https://rest-coast.eu/storage/app/media/pilots/Wadden%20Sea_2022.pdf (accessed on 25 October 2025).
16. Slusser, J.L.; Calle, A.; Garen, E. 1.2 Sustainable Ranching and Restoring Forests in Agricultural Landscapes, Panama. 2015. Available online: <https://hdl.handle.net/10088/28940> (accessed on 25 October 2025).
17. Temmerman, S.; Horstman, E.M.; Krauss, K.W.; Mullarney, J.C.; Pelckmans, I.; Schoutens, K. Marshes and mangroves as nature-based coastal storm buffers. *Annu. Rev. Mar. Sci.* **2023**, *15*, 95–118. [\[CrossRef\]](#)
18. Gracia, V.; Sierra, J.P.; Caballero, A.; García-León, M.; Mössö, C. A methodological framework for selecting an optimal sediment source within a littoral cell. *J. Environ. Manag.* **2021**, *296*, 113207. [\[CrossRef\]](#)
19. Newton, A.; Icely, J.; Cristina, S.; Perillo, G.M.E.; Turner, R.E.; Ashan, D.; Cragg, S.; Luo, Y.; Tu, C.; Li, Y.; et al. Anthropogenic, direct pressures on coastal wetlands. *Front. Ecol. Evol.* **2020**, *8*, 144. [\[CrossRef\]](#)
20. Wu, W.; Wan, L. Coastal ecological and environmental management under multiple anthropogenic pressures: A review of theory and evaluation methods. In *Current Trends in Estuarine and Coastal Dynamics*; Wang, X.H., Qiao, L., Mitchell, S., Elliott, M., Eds.; Elsevier: Amsterdam, The Netherlands, 2024; Volume 4, pp. 385–415. [\[CrossRef\]](#)
21. Morris, R.L.; Konlechner, T.M.; Ghisalberti, M.; Swearer, S.E. From grey to green: Efficacy of eco-engineering solutions for nature-based coastal defence. *Glob. Change Biol.* **2018**, *24*, 1827–1842. [\[CrossRef\]](#)
22. Apine, E.; Stojanovic, T. Is the coastal future green, grey or hybrid? Diverse perspectives on coastal flood risk management and adaptation in the UK. *Camb. Prisms Coast. Futures* **2024**, *2*, e4. [\[CrossRef\]](#)
23. Cheong, S.-M.; Silliman, B.; Wong, P.P.; van Wesenbeeck, B.; Kim, C.-K.; Guannel, G. Coastal adaptation with ecological engineering. *Nat. Clim. Change* **2013**, *3*, 787–791. [\[CrossRef\]](#)
24. Temmerman, S.; Meire, P.; Bouma, T.J.; Herman, P.M.J.; Ysebaert, T.; De Vriend, H.J. Ecosystem-based coastal defence in the face of global change. *Nature* **2013**, *504*, 79–83. [\[CrossRef\]](#)
25. Kisacik, D.; Tarakcioglu, G.O.; Cappietti, L. Adaptation measures for seawalls to withstand sea-level rise. *Ocean Eng.* **2022**, *250*, 110958. [\[CrossRef\]](#)
26. Singhvi, A.; Luijendijk, A.P.; van Oudenhoven, A.P.E. The grey–green spectrum: A review of coastal protection interventions. *J. Environ. Manag.* **2022**, *311*, 114824. [\[CrossRef\]](#) [\[PubMed\]](#)
27. Danley, B.; Widmark, C. Evaluating conceptual definitions of ecosystem services and their implications. *Ecol. Econ.* **2016**, *126*, 132–138. [\[CrossRef\]](#)
28. Spencer, T.; Temmerman, S.; Kirwan, M.L.; Wolff, C.; Lincke, D.; McOwen, C.J.; Pickering, M.D.; Reef, R.; Vafeidis, A.T.; Hinkel, J.; et al. Future response of global coastal wetlands to sea-level rise. *Nature* **2018**, *561*, 231–234. [\[CrossRef\]](#)
29. Bax, V.; van de Lageweg, W.I.; Terpstra, T.; Buijs, J.-M.; de Reus, K.; de Groot, F.; van Schaik, R.; Habte, M.A.; Schram, J.; Hoogenboom, T. The impact of coastal realignment on the availability of ecosystem services: Gains, losses and trade-offs from a local community perspective. *J. Environ. Manag.* **2023**, *345*, 118675. [\[CrossRef\]](#) [\[PubMed\]](#)
30. Weaver, R.J.; Stehno, A.L. Mangroves as coastal protection for restoring low-energy waterfront property. *J. Mar. Sci. Eng.* **2024**, *12*, 470. [\[CrossRef\]](#)
31. Gann, G.D.; McDonald, T.; Walder, B.; Aronson, J.; Nelson, C.R.; Jonson, J.; Hallett, J.G.; Eisenberg, C.; Guariguata, M.R.; Liu, J.; et al. International principles and standards for the practice of ecological restoration. *Restor. Ecol.* **2019**, *27* (Suppl. S1), S1–S46. [\[CrossRef\]](#)
32. Holl, K.D. *Primer of Ecological Restoration*; Island Press: Washington, DC, USA, 2020; ISBN 9781610919739.
33. Cairns, S.; Dudley, N.; Hall, C.; Keeneleyside, K.; Stolton, S. *Ecological Restoration for Protected Areas: Principles, Guidelines and Best Practices*; IUCN: Gland, Switzerland, 2012; ISBN 978-2-8317-1533-9. Available online: <https://portals.iucn.org/library/node/10205> (accessed on 31 August 2025).
34. Prach, K.; Durigan, G.; Fennessy, S.; Overbeck, G.E.; Torezan, J.M.; Murphy, S.D. A primer on choosing goals and indicators to evaluate ecological restoration success. *Restor. Ecol.* **2019**, *27*, 917–923. [\[CrossRef\]](#)

35. Mestres, M.; Ebro Delta Team. Ebro Delta Pilot Fact Sheet. 2024. Available online: https://rest-coast.eu/storage/app/media/pilots/Ebro%20Delta_2024.pdf (accessed on 25 October 2025).
36. Li, X.; Lin, S.; Qian, L.; Wang, Z.; Cao, C.; Gao, Q.; Cai, J. Characteristics and evaluation of living shorelines: A case study from Fujian, China. *J. Mar. Sci. Eng.* **2025**, *13*, 1307. [\[CrossRef\]](#)
37. Lees, E.; Pedersen, O.W. Restoring the regulated: The EU's Nature Restoration Law. *J. Environ. Law* **2025**, *37*, eqae032. [\[CrossRef\]](#)
38. European Commission. *Restoring Ecosystems Under the Green Deal Call: Recovering Biodiversity and Connecting to Nature*; Publications Office of the European Union: Luxembourg, 2024. Available online: <https://data.europa.eu/doi/10.2777/675374> (accessed on 25 October 2025).
39. Hering, D.; Schürings, C.; Wenskus, F.; Blackstock, K.; Borja, A.; Birk, S.; Bullock, C.; Carvalho, L.; Dagher-Kharrat, M.B.; Lakner, S.; et al. Securing success for the Nature Restoration Laws. *Science* **2023**, *382*, 1248–1250. [\[CrossRef\]](#)
40. Cortina-Segarra, J.; García-Sánchez, I.; Grace, M.; Andrés, P.; Baker, S.; Bullock, C.; Decler, K.; Dicks, L.V.; Fisher, J.L.; Frouz, J.; et al. Barriers to ecological restoration in Europe: Expert perspectives. *Restor. Ecol.* **2021**, *29*, e13346. [\[CrossRef\]](#)
41. Hinkel, J.; Aerts, J.C.J.H.; Brown, S.; Jiménez, J.A.; Lincke, D.; Nicholls, R.J.; Scussolini, P.; Sanchez-Arcilla, A.; Vafeidis, A.; Addo, K.A. The ability of societies to adapt to twenty-first-century sea-level rise. *Nat. Clim. Change* **2018**, *8*, 570–578. [\[CrossRef\]](#)
42. Affolder, N. Transnational conservation contracts. *Leiden J. Int. Law* **2012**, *25*, 443–460. [\[CrossRef\]](#)
43. Caneva, G.; Ceschin, S.; Lucchese, F.; Scalici, M.; Battisti, C.; Tufano, M.; Tullio, M.C.; Cicinelli, E. Environmental management of waters and riparian areas to protect biodiversity through River Contracts: The experience of Tiber River (Rome, Italy). *River Res. Appl.* **2021**, *37*, 1510–1519. [\[CrossRef\]](#)
44. Demant, L.; Bergmeier, E.; Walentowski, H.; Meyer, P. Suitability of contract-based nature conservation in privately-owned forests in Germany. *Nat. Conserv.* **2020**, *42*, 89–112. [\[CrossRef\]](#)
45. Lindsay, B. Legal instruments in private land conservation: The nature and role of conservation contracts and conservation covenants. *Restor. Ecol.* **2016**, *24*, 698–703. [\[CrossRef\]](#)
46. Sánchez-Arcilla, A.; Cáceres, I.; Roux, X.L.; Hinkel, J.; Schuerch, M.; Nicholls, R.J.; Staneva, J.; de Vries, M.; Pernice, U.; Briere, C.; et al. Barriers and enablers for upscaling coastal restoration. *Nat.-Based Solut.* **2022**, *2*, 100032. [\[CrossRef\]](#)
47. Lazzari, N.; Becerro, M.A.; Martín-López, B. Assessing social-ecological vulnerability of coastal systems to fishing and tourism. *Sci. Total Environ.* **2021**, *784*, 147078. [\[CrossRef\]](#)
48. Waltham, N.J.; Elliott, M.; Lee, S.Y.; Lovelock, C.; Duarte, C.M.; Buelow, C.; Simenstad, C.; Nagelkerken, I.; Claassens, L.; Wen, C.K.-C.; et al. UN Decade on Ecosystem Restoration 2021–2030—What chance for success in restoring coastal ecosystems? *Front. Mar. Sci.* **2020**, *7*, 71. [\[CrossRef\]](#)
49. Fernandino, G.; Elliff, C.I.; Silva, I.R. Ecosystem-based management of coastal zones in face of climate change impacts: Challenges and inequalities. *J. Environ. Manag.* **2018**, *215*, 32–39. [\[CrossRef\]](#)
50. Day, J.W.; Rybczyk, J.M. Global change impacts on the future of coastal systems: Perverse interactions among climate change, ecosystem degradation, energy scarcity, and population. In *Coasts and Estuaries*; Wolanski, E., Day, J.W., Elliott, M., Ramachandran, R., Eds.; Elsevier: Amsterdam, The Netherlands, 2019; pp. 621–639. [\[CrossRef\]](#)
51. Mayes, W.M.; Batty, L.C.; Younger, P.L.; Jarvis, A.P.; Köiv, M.; Vohla, C.; Mander, U. Wetland treatment at extremes of pH: A review. *Sci. Total Environ.* **2009**, *407*, 3944–3957. [\[CrossRef\]](#)
52. Motta Zanin, G.; Muwafu, S.P.; Máñez Costa, M. Nature-based solutions for coastal risk management in the Mediterranean basin: A literature review. *J. Environ. Manag.* **2024**, *356*, 120667. [\[CrossRef\]](#)
53. Nicholls, R.J.; Woodroffe, C.; Burkett, V. Chapter 20—Coastline degradation as an indicator of global change. In *Climate Change*, 2nd ed.; Letcher, T.M., Ed.; Elsevier: Amsterdam, The Netherlands, 2016; pp. 309–324. [\[CrossRef\]](#)
54. Gladstone-Gallagher, R.V.; Thrush, S.F.; Low, J.M.L.; Sa Pilditch, C.A.; Ellis, J.I.; Hewitt, J.E. Toward a network perspective in coastal ecosystem management. *J. Environ. Manag.* **2023**, *346*, 119007. [\[CrossRef\]](#)
55. Macreadie, P.I.; Costa, M.D.P.; Atwood, T.B.; Friess, D.A.; Kelleway, J.J.; Kennedy, H.; Lovelock, C.E.; Serrano, O.; Duarte, C.M. Blue carbon as a natural climate solution. *Nat. Rev. Earth Environ.* **2021**, *2*, 826–839. [\[CrossRef\]](#)
56. Zennaro, F.; Furlan, E.; Canu, D.; Alcazar, L.A.; Rosati, G.; Solidoro, C.; Critto, A. Hypoxia extreme events in a changing climate: Machine learning methods and deterministic simulations for future scenarios development in the Venice Lagoon. *Mar. Pollut. Bull.* **2024**, *208*, 117028. [\[CrossRef\]](#)
57. Anisfeld, S. *Water Management: Prioritizing Justice and Sustainability*; Island Press: Washington, DC, USA, 2024; ISBN 9781642830064.
58. Feagin, R.A.; Lerner, J.E.; Noyola, C.; Huff, T.P.; Madewell, J.; Balboa, B. Hypersalinity in coastal wetlands and potential restoration solutions, Lake Austin and East Matagorda Bay, Texas, USA. *J. Mar. Sci. Eng.* **2024**, *12*, 829. [\[CrossRef\]](#)
59. Fernow, B.E. *A Brief History of Forestry: In Europe, the United States and Other Countries*; DigiCat: Boston, MA, USA, 2022. Available online: <https://www.gutenberg.org/files/48874/48874-h/48874-h.htm> (accessed on 31 August 2025).
60. Musumeci, R.E.; Marino, M.; Cavallaro, L.; Foti, E. Does coastal wetland restoration work as a climate change adaptation strategy? The case of the south-east of Sicily coast. *Coast. Eng. Proc.* **2022**, *37*, 66. [\[CrossRef\]](#)

61. Gusmaroli, G.; Dodaro, G.; Schipani, I.; Perin, C.; Alberti, F.; Magaudo, S. Wetland Contracts: Voluntary-Based Agreements for the Sustainable Governance of Mediterranean Protected Wetlands. In *Recent Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions*; Ksibi, M., Ghorbal, A., Chakraborty, S., Chaminé, H.I., Barbieri, M., Guerriero, G., Hentati, O., Negm, A., Lehmann, A., Römbke, J., et al., Eds.; Springer International Publishing: Cham, Switzerland, 2021; pp. 2157–2160. [\[CrossRef\]](#)
62. Garen, E.J.; Saltonstall, K.; Ashton, M.S.; Slusser, J.L.; Mathias, S.; Hall, J.S. The tree planting and protecting culture of cattle ranchers and small-scale agriculturalists in rural Panama: Opportunities for reforestation and land restoration. *For. Ecol. Manag.* **2011**, *261*, 1684–1695. [\[CrossRef\]](#)
63. Holl, K.D. Restoring tropical forests from the bottom up. *Science* **2017**, *355*, 455–456. [\[CrossRef\]](#)
64. Dalle, J.; Briere, C. Arcachon Bay Pilot Fact Sheet. Available online: https://rest-coast.eu/storage/app/media/pilots/Arcachon_Bay_english.pdf (accessed on 31 August 2025).
65. USDA; USFS. Stewardship Contracting: Basic Stewardship Contracting Concepts. 2009. Available online: https://www.fs.usda.gov/restoration/documents/stewardship/stewardship_brochure.pdf (accessed on 25 October 2025).
66. Abrams, J.; Burns, S. *Case Study of a Community Stewardship Success: The White Mountain Stewardship Contract*; Northern Arizona University: Flagstaff, AZ, USA, 2007. Available online: https://openknowledge.nau.edu/id/eprint/1294/1/Abrams_Burns_2007_ERIWhitePaper_CaseStudyOfACommunity.pdf (accessed on 25 October 2025).
67. Gusmaroli, G. Dieci anni di Contratti di Fiume in Italia: Dai Risultati del Primo Censimento alla Proposta di un Osservatorio. VII Tavolo Nazione dei Contratti di Fiume, Bologna. 2012. Available online: <https://partecipa.gov.it/assemblies/contratti-di-fiume> (accessed on 25 October 2025).
68. Campostrini, P.; Dabalà, C.; Coccon, F.; Torresan, S.; Furlan, E.; Horneman, F.; Critto, A.; Pranovi, F.; Rova, S.; Barausse, A.; et al. Venice Lagoon Pilot Fact Sheet. 2024. Available online: https://rest-coast.eu/storage/app/media/pilots/Venice%20Lagoon_2024.pdf (accessed on 31 August 2025).
69. Ernoul, L.; Vera, P.; Gusmaroli, G.; Muccitelli, S.; Pozzi, C.; Magaudo, S.; Horvat, K.P.; Smrekar, A.; Satta, A.; Monti, F. Use of voluntary environmental contracts for wetland governance in the European Mediterranean region. *Mar. Freshw. Res.* **2021**, *73*, 1166–1173. [\[CrossRef\]](#)
70. Różyński, G. Vistula Lagoon Artificial Island Pilot Fact Sheet. 2024. Available online: https://rest-coast.eu/storage/app/media/pilots/Vistula_2024.pdf (accessed on 25 October 2025).
71. Jackson, D.W.T.; Cooper, J.A.G. Geological control on beach form: Accommodation space and contemporary dynamics. *J. Coast. Res.* **2009**, *1*, 69–72. Available online: <http://www.jstor.org/stable/25737539> (accessed on 25 October 2025).
72. Hüskens, L.M.; Slinger, J.H.; de Rijk, S.; Altamirano, M.A.; Vreugdenhil, H.S. Overcoming financial barriers to ecological restoration—The case of the Marker Wadden. *Ecol. Eng.* **2025**, *219*, 107706. [\[CrossRef\]](#)
73. Howson, P.; Oakes, S.; Baynham-Herd, Z.; Swords, J. Cryptocarbon: The promises and pitfalls of forest protection on a blockchain. *Geoforum* **2019**, *100*, 1–9. [\[CrossRef\]](#)
74. Liu, X.; Dong, F.; Shui, W.; Geng, G. Blockchain in digital cultural heritage resources: Technological integration, consensus mechanisms, and future directions. *NPJ Herit. Sci.* **2025**, *13*, 235. [\[CrossRef\]](#)
75. Liu, F.H.M.; Thompson, B.S.; Harris, J.L. Financing forest restoration: The distribution and role of green FinTech in nature-based solutions to climate change. *Financ. Space* **2025**, *2*, 159–187. [\[CrossRef\]](#)
76. Favero, F.; Hinkel, J. Key innovations in financing nature-based solutions for coastal adaptation. *Climate* **2024**, *12*, 53. [\[CrossRef\]](#)
77. Bell-James, J.; Fitzsimons, J.A.; Lovelock, C.E. Land tenure, ownership and use as barriers to coastal wetland restoration projects in Australia: Recommendations and solutions. *Environ. Manag.* **2023**, *72*, 179–189. [\[CrossRef\]](#)

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