Policy Brief

REST~COAST

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Connectivity's role in maintaining coastal resilience

Key insights from restoration initiatives to enhance source-to-sea connectivity

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Executive Summary

Coastal areas are strategic ecological zones where land and sea converge, supporting rich biodiversity and delivering key ecosystem services. Their health, productivity, and stability rely on strong **connectivity**, which ensures not only critical ecological functions such as nutrient cycling, reproduction, migration, habitat regeneration, but also sediment supply and dynamics. Yet, coastal ecosystems have experienced decline and fragmentation over recent decades, driven largely by pressures from human activities, including coastal development, pollution, and the impacts of climate change. In this context, restoring coastal ecosystems and enhancing their connectivity are interdependent goals, each reinforcing the other to promote ecological resilience and long-term sustainability.

The integration of connectivity into conservation planning and decision-making has been limited by challenges involved in quantifying and measuring its role in supporting habitats and species. This is especially true in coastal and marine systems, where the inherent openness and its temporal and spatial variability make connectivity difficult to assess, and its ecological impacts harder to predict. Nonetheless, connectivity has been gaining traction in environmental policy due to its key vital role in ecosystem functioning and resilience. This growing recognition is exemplified by its inclusion in international frameworks such as the Kunming-Montreal Global Biodiversity Framework.

This policy brief aims to advance the discussion on connectivity in coastal areas by outlining key considerations for its definition, management practices, monitoring and benefits to ecosystem services. Drawing on insights from the REST-COAST project, this document also provides recommendations (summarized below) to restoring coastal connectivity and its operationalisation with valuable insights into how integrating connectivity can enhance conservation and restoration outcomes, cost-effectiveness, and spatial planning.

Policy recommendations summary

UNIFIED APPROACH TO COASTAL CONNECTIVITY

Consider developing clear guidance on how to incorporate a shared operational definition of coastal connectivity into spatial planning and relevant strategies and initiatives at EU and national levels (incl. restoration, such as the NRR).

STRATEGIC SPATIAL PLANNING

When planning restoration, consider prioritising areas where improving connectivity will have the greatest impact on conservation outcomes.

POLICY AND GOVERNANCE COHERENCE

To support effective restoration of coastal ecosystems but considering connectivity, stronger institutional coordination among sectors, agencies, and stakeholders would be beneficial.

CROSS-BORDER COOPERATION

As coastal and marine ecosystems often extend beyond administrative and national boundaries, connectivity could be key when addressing transboundary collaboration for restoration.

METRICS AND INDICATORS

It would be helpful to operationalise robust indicators that capture the key structural and functional aspects of ecosystems, with particular attention to the interconnected source-to-sea nature dynamics of coastal ecosystems.

ADAPTIVE MANAGEMENT FOR CLIMATE RESILIENCE

Coastal connectivity plays a key role in enabling species and habitat networks to cope with climate change by supporting key ecological and physical processes related to littoral dynamics. Therefore, it would be beneficial to consider incorporating the potential positive contributions of improved coastal connectivity into climate scenario prediction models.

1 Introduction

1.1 Why is connectivity important in coastal areas?

Home to some of the world's richest and most unique biodiversity, **coastal ecosystems** – including wetlands, estuaries, dunes and seagrass meadows – are at the interface between land, sea, and atmosphere. Considering their position at this intersection, these ecosystems **rely on strong connectivity across ecoscapes (landscapes and seascapes) to function effectively**. Connectivity between and within coastal ecosystems enables the movement of species across habitats and sustains vital ecological processes like seed or larval dispersal and nutrient flows, linking waterways to the ocean. Connectivity also enables water, sediment and nutrient fluxes that enhance natural resilience. These processes, in turn, contribute to the long-term health of coastal, marine, and terrestrial environments, providing ecosystem services for economies and well-being, and enhances coastal resilience to the effects of climate change (Sheaves, 2009).

Over the years, however, both the condition and cover of coastal habitats have steadily declined and become increasingly fragmented across the ecoscape. This is not entirely surprising, given that almost 40% of the EU's population lives within 50 km of the coast and most of the economic activity is concentrated here and is expected to increase in the future (European Commission, 2024). **Coastal ecosystems are under multiple pressures** from human activities, including urban development, pollution, tourism, agriculture, overfishing, and industrial expansion (Innocenti & Musco, 2023). As a result, **only 8% of the EU's coastal habitats are currently considered in good condition, and 45% of coastal habitats evaluated by the European Red List of Habitats are considered to be threatened with extinction** (EEA, 2020; Janssen *et al.*, 2016). Climate change is expected to further exacerbate these pressures, with rising sea levels, more frequent storm surges and coastal erosion further threatening already vulnerable coastal ecosystems and communities (Cooley *et al.*, 2022).

As development, land-use change and climate impacts continue to fragment these ecoscapes, connectivity has emerged as a key aspect of conservation efforts. For instance, the Kunming-Montreal Global Biodiversity Framework highlights connectivity as a key component of its goals, with several specific targets mentioning this concept (CBD, 2022). Well-functioning and resilient ecosystems need to be connected to maintain key ecological processes and deliver ecosystem services. Isolated, small patches, for instance, are a threat to species because they only support smaller populations, resulting in less genetic diversity, more extinction threats and exposure to edge effects (an increase or decline in abundance or occurrence of a species at the boundary between two habitats). There is now a growing understanding within the conservation community of the necessity to move beyond the protection and conservation of species and habitats in isolation and to ensure that key ecological processes are also maintained to support and sustain biodiversity. Wildlife corridors, habitat patches, stepping-stones, and other spatial linkages have gained prominence in the debate as tools able to restore natural connections, linking important habitats, supporting species movement, and sustaining ecosystem functions in highly fragmented terrestrial, freshwater, coastal, and marine areas (Hilty *et al.*, 2020).

Moreover, coastal regions represent complex socio-ecological systems, shaped by the interactions of diverse sectors, stakeholders, and governance levels (Kern & Gilek, 2016). These systems are commonly managed in a more fragmented manner, with the authorities involved operating in silos under different policy frameworks, objectives, and timelines. Such fractured governance can hinder effective conservation and restoration across the land-sea continuum. Strengthening ecosystem resilience and connectivity across landscapes and seascapes requires integrated, cross-sectoral collaboration that bridges institutional and jurisdictional boundaries. Aligning spatial planning, infrastructure development, agricultural practices, and coastal and marine management is essential to reduce fragmentation, restore functional ecological linkages, and enable more adaptive, climate-resilient coastal systems. Furthermore, in transboundary contexts, coordination is crucial to ensure coherent and mutually reinforcing actions across shared coastal and marine ecosystems.

1.2 Understanding the concept of connectivity

Connectivity, in broad terms, refers to the **movement of materials, energy and living organisms across space** (Beger *et al.*, 2022). This concept captures the dynamic aspects of nature, encompassing the complex network of patterns and interactions that underpin biodiversity, support ecosystem functioning and enhance resilience to climate change. Yet, despite its importance, the concept remains fragmented, especially where marine and coastal ecosystems are concerned. Definitions differ across disciplines, each bringing distinct implications for conservation (Keely *et al.*, 2021). Therefore, understanding and bridging these different conceptualisations is necessary for a more unified approach that acknowledges the multiple dimensions of connectivity and ensures that all elements of this multifaceted concept are appropriately considered. Within the nature conservation community, **ecological connectivity** is defined as the "***unimpeded movement of species, connection of habitats without hinderance, and the flow of natural processes that sustain life on Earth***" (CMS, 2024). According to the definition from the IUCN's "*Guidelines for conserving connectivity through ecological networks and corridors*" (Hilty *et al*., 2020), in the context of protected areas, there are various sub-definitions of the concept including: 1) **ecological connectivity** for species (scientific-detailed definition); 2) **functional connectivity for species**; and 3) **structural connectivity for species**. Many species rely on movement to survive and reproduce. Moving allows access to food, suitable habitats and mates, while evading threats such as predation, competition from other individuals and depleted habitats. Moreover, these movements allow for increased genetic exchange, making species more genetically diverse and adaptable, as well as shift in their natural ranges, which helps them adapt to changing conditions and climate change (Moreira *et al*., 2024). The movement of species, in turn, supports broader ecological processes that are central to ecosystems well-functioning, including nutrient cycling, pollination, soil erosion and water flow.

Connectivity encompasses not only the movement of organisms across different habitats and life stages (e.g., propagules, larvae, adults) but also considers the underlying **ecological processes** across habitats or ecosystems (e.g., exchange of water, nutrients, and energy). Following this, the concept of ecological connectivity can be divided into two distinct types, each of which is assessed using different methods:

- **Structural connectivity** considers the physical characteristics that support or impede the connection of landscapes and the movement of organisms, based on physical arrangements and the distribution of habitat patches. It is often used to estimate functional connectivity when direct measures to assess it are lacking.

- **Functional connectivity** describes how well organisms, genes, reproductive material and processes (including seed dispersal, breeding migrations, genetic exchange) can move within ecoscapes, considering not only the physical features of a habitat, but also how specific species respond to it. This type of connectivity is species-specific and may depend on changing environmental conditions in time and space.

When considering both structural and functional connectivity, habitats may be structurally connected to each other, but not functionally – and vice versa (Keeley *et al*., 2021).

Furthermore, connectivity operates across multiple spatial and temporal dimensions, particularly for aquatic ecosystems that operate at a three-dimensional level. For aquatic ecosystems, **longitudinal connectivity** describes the upstream and downstream connections, or the flow from water sources to the sea. **Lateral connectivity** is concerned with the connection between waterbodies (rivers, wetlands, waterways) and the adjacent area, while **vertical connectivity** describes the connection between groundwater and surface waters (Moberg *et al*., 2024). Given the interconnected nature of aquatic ecosystems, many species depend on multiple habitats throughout their life cycle and might even move between different ecological realms (terrestrial, freshwater, coastal, marine) (Beger *et al*., 2010). For example, seagrass meadows and saltmarshes serve as nursery grounds for fish that later migrate to deeper waters (Erzini *et al*., 2022; Whitfield, 2017).

Overall, marine species have relatively large dispersal distances, and although many coastal species are more sedentary during mature stages of the life cycle, they rely on connectivity during reproductive stages (e.g., dispersal eggs or larvae through currents or other mechanisms underpinning connectivity) (Beger *et al*., 2010). Changes in connectivity, for example, due to artificial barriers (e.g., river dams, dikes) or fragmentation by land uses (e.g., agriculture, coastal development, industry), will thus impact which species will be able to reach, inhabit or move a specific habitat or ecosystem.

Additionally, connectivity can be assessed at various scales, which may feature different fluxes and movement behaviours. These include at the local scale (home range fluxes or movements), landscape scale (dispersal movements away from natal range and river to coast fluxes), and regional/global scale (those linked to long-distance migrations to track seasonable availabilities in resources) (Brodie *et al*., 2025). Traditionally, connectivity research and planning have focused more on the individual movement of different species and local fluxes, tackling how this is supported across these different levels. While ecological processes – such as hydrological changes, sediment transport, and energy fluxes – are particularly important for understanding the intricate dynamics of coastal connectivity and their impact on the composition and functioning of these areas. Therefore, **measuring – and considering – different dimensions of coastal connectivity is essential to understand and manage key environmental functions such as species composition, water quality, carbon and nutrient storage, and food web stability and ensure that ecosystems are well-connected from water sources to the sea.**

2 Key considerations for coastal connectivity

Advances in conservation research have improved the understanding of connectivity in coastal ecosystems. Coastal connectivity involves physical, chemical and biological processes that determine the structure and function of these ecosystems. However, assessing its different facets is particularly challenging due to the openness, variability, and constant change in coastal environments. Coastal ecosystems are, for instance, characterised by shifting conditions, such as salinity, temperature, oxygen levels, turbidity, currents, tides, and wave exposure. This also makes them highly sensitive to both natural and human-induced changes.

While research is still emerging and knowledge gaps remain, growing evidence offers valuable insights for conservation planning and restoration of coastal ecosystems. For instance, definitions, perspectives, conceptualisations and methodologies of coastal connectivity might differ across different relevant disciplines (marine ecology, environmental sciences, coastal engineering) and might focus on one or multiple dimensions, including hydrological, sediment and cross-realm connectivity. Moreover, social sciences (e.g., socio-economic, governance) have contributed insights based on a broader approach to coastal connectivity, including the importance of coordination across sectors, stakeholders, governance levels and borders for a coordinated approach that considers coastal connectivity.

While closely linked, hydrological and sediment connectivity require different considerations for conservation efforts (Box 1). For example, sediment transport is more dependent on structural connectivity than hydrological connectivity and is particularly impacted by heavy rainfall conditions, which makes its consideration particularly relevant in a changing climate (Tiwari *et al*., 2025).

Another key consideration for coastal ecosystems is **cross-realm connectivity,** which considers the benefits and trade-offs across freshwater, terrestrial, coastal and marine realms. This type of connectivity is key for species that rely on different realms throughout their life cycle, use different realms daily or seasonally, or that may be impacted from threats propagating from other realms. Understanding dependencies across multiple realms in conservation planning can, for instance, be helpful to identify priority areas for the conservation of multiple species and maintain ecosystem functions. Such an approach extends beyond simply addressing threat propagation from one realm to another or focusing on individual species, allowing to account for asymmetric and complex inter-realm relationships that may shape conservation outcomes and the delivery of ecosystem services. Considering cross-realm connectivity can particularly be helpful when planning restoration measures at regional scale (Hermoso *et al*., 2021).

Moreover – in relation to a broader approach to coastal connectivity – it would be relevant to consider the complex governance structure of coastal areas. Most coastal areas involve many different actors from various sectors, as well as institutional bodies operating at different levels with distinct, and sometimes conflicting, mandates. Given that coastal areas are located at the land-sea continuum, they are both shaped by upstream conditions (e.g., water flows and quality) and dynamic ocean conditions (e.g., current, tides and wave energy). This would require coordinated governance across the land-sea interface, which has traditionally been managed separately by different institutions. For instance, different institutional bodies have been responsible for land-based activities (agriculture, forestry, urban), water management, coastal protection, and the marine environment. Additionally, the impacts and connectivity of coastal ecosystems may span different jurisdictions, as recognised by the UN Regional Sea Conventions, which cover specific areas such as the Mediterranean, Baltic and Black Seas.

Many human activities take place in coastal areas where different sectors and actors are involved. A key consideration for coastal connectivity here is the impact of ocean sprawl – the artificial structures put in place by coastal development, industry, and infrastructure – which may have fragmented habitats or disrupted species movement, or, in some cases, created new corridors for connectivity that may facilitate nutrient runoff and chemical pollution from agriculture and industry (Bishop *et al*., 2017). The concept of **land-sea interactions** aims to capture the complexity of these natural and socio-economic processes on coastal ecosystems and provides a framework for integrated governance across the land-sea continuum (Tocco *et al*., 2024). Here, a *'landscape finance'* framework comprising tailored, innovative blended (public and private) financing solutions based on multi-stakeholder partnerships could benefit the maintenance and enhancement of connectivity at the landscape scale to coordinate action and reduce investment risks (Bertels *et al*., 2023).

Hydrological connectivity, for one, is considered essential for the functioning of freshwater, coastal, and marine ecosystems. It refers to the movement of water – and the organisms, nutrients, and energy it carries – through aquatic systems**.** This movement is shaped by fluctuations in water volume, flow rates, and the natural characteristics of the landscape, among others. Because these factors vary by location and season, waterbodies also differ in how often and strongly they stay connected to one another. Over time, aquatic species have evolved to synchronise with the patterns and timescales of variability within the hydrological cycle. Disruptions to this connectivity, such as those caused by dams, dykes or changes in land-use as well as those caused by extreme weather events, can alter habitat conditions and determine which species may thrive in a specific habitat, and which may not. These changes in connectivity not only affect biodiversity and species composition in a certain habitat, but also influence how water moves nutrients, sediment and organisms across landscapes, which may further alter ecosystem functions and composition both in the upstream and downstream direction (Bracken *et al.*, 2013).

Sediment connectivity – the transfer of sediment from different sections of landscapes at various spatial and temporal scales – is equally critical for maintaining the structure and function of coastal ecosystems (Najafi *et al.*, 2021; Bracken *et al.*, 2015). It ensures the delivery of sand, silt, and nutrients that build shorelines, support wetlands, and maintain floodplains. Disruptions caused by river modifications, deforestation, agriculture, or sediment extraction can interrupt this flow, leading to coastal erosion, delta subsidence, habitat loss, and declined fertility of floodplains, due to the insufficient delivery of sediments to these areas. Coastal vegetation such as seagrass meadows, saltmarshes and kelp forests, can play a critical role in stabilizing sediments and limiting runoff, and their continued loss therefore also limits coastal resilience against the impacts of climate change, including sea-level rise and extreme weather events.

Box 1. Hydrological connectivity vs Sediment connectivity

3 How is coastal connectivity addressed by international and EU policy?

A sound understanding of coastal connectivity – and the tools to maintain it effectively – is critical for its integration into key policy frameworks, environmental agreements, and large-scale conservation efforts. Its understanding could further provide guidance for sustainable practices for key economic sectors such as agriculture, maritime transport, fisheries, urban development, tourism, and extractive industries, all of which depend on coastal ecosystems and the services they provide. Although connectivity considerations have been receiving more attention globally, progress towards a coherent definition and more unified methods and metrics to assess connectivity for marine and coastal ecosystems could be further extended in the environmental acquis.

3.1 International context

While the issue of ecological connectivity is of fundamental importance in several multilateral environmental agreements and conventions – e.g., the Convention on Migratory Species (CMS) and the UN Regional Sea Conventions- it is key to focus on the inclusion of the concept in the Kunming-Montreal Global Biodiversity Framework (GBF). The GBF is an ambitious plan to protect biodiversity and live in harmony with nature by 2050 under the auspices of the UN Convention on Biological Diversity (CBD). Within this framework, **there is a clear recognition of the role of connectivity in achieving global biodiversity conservation and wider societal goals.** This is reflected in **Goal A**, which aspires to enhance the integrity, connectivity and resilience of all ecosystems to conserve biodiversity and deliver ecosystem services. The GBF includes specific mentions in Target 2 on ecosystem restoration, Target 3 on ecologically representative protected areas, and Target 12 on urban planning. It could also be considered a key aspect of Target 1 on spatial planning, where the CBD has issued an assessment on ecological connectivity for inclusive spatial planning by 2027. Some elements in other targets can also be considered relevant for connectivity (e.g., pathogen spillover in Target 5 and invasive alien species in Target 6).

More generally, connectivity considerations can facilitate a more concerted and effective implementation of the GBF by putting the focus on establishing and maintaining intact ecosystems across landscapes.[1] This UN Decade on Restoration 2021-2030 could support progress in this regard by effective advances in this regard by explicitly considering connectivity when deciding the location of restoration efforts (Brodie *et al.*, 2025). The Global Partnership on Ecological Connectivity under CMS, which aims to provide a multi-stakeholder platform to extend knowledge and collaboration for connectivity practices worldwide, could also contribute to support signatory parties on their progress made for connectivity.

[1] Other key relevant international conventions for coastal conservation may include the UN Climate Conference, the CITES Convention, the CMS Convention, the Berne Convention, the RAMSAR Convention, the different UN Regional Sea Conventions, and the UN Decade on Restoration.

Although the GBF sets out general objectives for improving connectivity, the accompanying monitoring framework provides the indicators against which progress towards these objectives will be measured. In the lead up to the adoption to the GBF, **specific indicators for connectivity** were only proposed in relation to Target 3, which may indicate that – although connectivity is very relevant for successful restoration and vice versa – the definition for metrics within the conservation community has been more advanced than for the restoration community up to now (Brodie *et al*., 2024).

The monitoring framework lists seven indicators in total that directly estimate connectivity and an additional two that focus on fragmentation.[2] Developed for terrestrial ecosystems, these indicators mainly address structural connectivity, while specific indicators for marine and coastal connectivity are currently not included. To better account for the unique dynamics of these ecosystems, and to advance conservations efforts to improve coastal connectivity, it would be valuable to test their applicability of these indicators and to incorporate functional connectivity indicators for marine and coastal ecosystems (e.g., hydrological, sediment, cross-realm, spillover) (Metaxas *et al*., 2024).

3.2 European context

The **EU Biodiversity Strategy for 2030** sets out a comprehensive plan to protect and conserve nature within the European Union. Aligned with the GBF, two of its key provisions are **to protect 30% of EU's land and sea, and to restore 20% of all degraded ecosystems**. This strategy notably emphasises the importance of increasing connectivity, intending to establish a trans-European network of protected and conserved areas. To achieve this, the strategy promotes ecological corridors, investments in green and blue infrastructure, and encourages cooperation among neighbouring countries.

Currently, approximately 12% of the EU's marine and coastal ecosystems are protected, with a significant portion (44%) comprising coastal ecosystems (EEA, 2024). The European Commission's guidance on protected areas (European Commission, 2022) **highlights the need to improve coherence and connectivity between sites, including Natura 2000 sites and other designated areas**. Although ecological corridors are recognised as important conservation tools, more guidance could better support decision-makers in understanding how to effectively address connectivity in coastal ecosystems, which are particularly complex due to their dynamic nature. Incorporating connectivity objectives – through restoration measures or Nature-based Solutions (NbS) – for various species and/or habitats into management plans could enhance their condition and overall resilience. This could be a key focus area for responsible authorities, given that currently only 2% of marine and coastal protected areas have such plans in place (EEA, 2024). An interesting conservation tool to support this can be the IUCN Guidance on "*Designing and managing protected and conserved areas to support inland water ecosystems and biodiversity*" (Moberg *et al*., 2024), which provides information on how to set environmental standards for marine, coastal and freshwater protected areas, focusing on environmental flows, water quality and connectivity.

Adopted in 2024, following the commitment outlined in the EU Biodiversity Strategy, the **EU Nature Restoration Regulation** (NRR) provides the first comprehensive legal framework for restoring degraded ecosystems across the EU (see **REST-COAST policy brief** on this topic). It sets legally binding restoration targets for Member States, who will need to outline how they are planning on meeting these objectives in their first National Restoration Plans, due by September 2027. Connectivity is a key component of the Regulation, particularly in relation to Articles 4 and 5 (restoration of freshwater, coastal and marine ecosystems, respectively) and Article 9 (removal of artificial barriers affecting surface water connectivity) (Box 2).

The NRR is complementary to the EU Birds and Habitats Directives, which together form the legal framework for protecting, conserving and restoring European habitats and species. These Directives underpin the Natura 2000 network as a key foundation for nature conservation planning in the EU. Both already provided provisions for improving ecological coherence of the network by promoting the establishment of functional connections. This includes implementing connectivity measures outside the Natura 2000 network to ensure the long-term well-being of habitats and species. The NRR will initially focus on the habitats and species listed in the Birds and Habitats Directives, adding time-bound restoration targets to improve their condition and further encourage coherence across protected and conserved areas.

Under the NRR, defining the "***favourable reference area***" – the minimum surface area necessary for the long-term viability of habitats and its typical species – is a key obligation under Articles 4 and 5. Connectivity can be considered a key factor in identifying areas for restoration or re-establishment, and in setting levels for favourable reference areas for habitats and species (Bijlsma *et al.*, 2017). Further guidance would be valuable on how to assess and incorporate connectivity, particularly for marine and coastal ecosystems, where an understanding of connectivity has been more difficult to establish compared to terrestrial environments. This is particularly

[2] The included connectivity indicators are; Bioclimatic Ecosystem Resilience Index (BERI), Dendritic Connectivity Index (DCI), Parc connectedness (Parc), Protected Area Isolation Index (PAI), Protected Areas Network metric (ProNet), Protected Connected Index (ProtConn and ConnIntact), with Biodiversity Habitat Index (BHI) and Relative Magnitude of Fragmentation (RMF) measuring degrees of fragmentation.

relevant in the framework of marine spatial planning, where integrating connectivity into policies, planning, and conservation has been highlighted (Podda & Porporato, 2023). Providing guidance would help ensure that restoration targets align with the spatial and functional requirements of ecosystems, increasing the effectiveness and long-term success of national restoration efforts.

Regarding marine and coastal ecosystems at the EU level, both the **Water Framework Directive** (WFD) and the **Marine Strategy Framework Directive** (MSFD) are two other key pieces of legislation within the EU environmental acquis. Under the WFD, Member States are required to develop River Basin Management Plans, including Programmes of Measures to improve the environmental status of the EU's inland, transitional, and coastal waters. Relevant for the REST-COAST project are the provisions for reducing the amount of pollution entering waterways, such as nutrient runoff from agriculture and chemical pollution from industry, and to manage ecological flows, the minimum hydrological requirements needed to maintain healthy and well-functioning aquatic ecosystems. It's important to reiterate that connectivity plays an important role in achieving the provisions of these two directives.

According to recent assessments, in the context of the WFD, most EU Member States have reported efforts to improve longitudinal connectivity (91%) and other hydromorphological conditions (79%), including measures such as fish passes, barrier removal, and river restoration to improve the condition of aquatic ecosystems. While these are positive developments, their implementation so far has been relatively slow, and the scale of restoration efforts remains limited in scope to fully restore the different facets of connectivity across freshwater, coastal, and marine environments. Definitions of ecological flows used also varied among EU Member States. Under the EU Floods Directive, another legislative piece of the complex EU water governance mosaic, several Member States have begun incorporating Nature-Based Solutions into their flood risk management plans with the potential to support greater coastal connectivity and improve natural defences in addition to traditional infrastructure, despite limited implementation so far (European Commission, 2025a).

With regard to the MSFD, the concept of connectivity takes on additional significance. Given the strong link between conditions upstream and the health of marine habitats, consideration for land-sea interactions would be key to reaching the Directive's objectives. This includes implementing measures to limit pollution and nutrient runoff from land that may directly affect marine habitats. Moreover, taking account of connectivity may support the strategic designation and management of Marine Protected Areas (MPAs) to support key ecological functions, especially regarding coastal ecosystems as transitional areas. For instance, to support the migration of fish to deeper waters. Broader considerations of connectivity may include stronger coordination across authorities and sectors, better alignment with other EU environmental policies, and enhanced transboundary cooperation with neighbouring countries. These could be further reinforced through the spatial plans laid out under the EU **Maritime Spatial Planning Directive**, as well as for the implementation of the Integrated Coastal Zone Management (ICZM) in the EU (European Commission, 2025; Zaucha *et al.*, 2025; Tocco *et al.*, 2024).

ARTICLE 4. Restoration of terrestrial, coastal and freshwater ecosystems

4.7. Member States shall put in place restoration measures for the terrestrial, coastal and freshwater habitats of the species listed in Annexes II, IV and V to Directive 92/43/EEC and of the terrestrial, coastal and freshwater habitats of wild birds falling within the scope of Directive 2009/147/EC that are, in addition to the restoration measures referred to in paragraphs 1 and 4 of this Article, ***necessary to improve the quality and quantity of those habitats, including*** by re-establishing them, and **to enhance connectivity**, *until sufficient quality and quantity of those habitats is achieved.*

ARTICLE 4.10. The restoration measures referred to in paragraphs 1 and 4 ***shall consider the need for improved connectivity*** *between the habitat types listed in Annex I and take into account the ecological requirements of the species referred to in paragraph 7 that occur in those habitat types.*

ARTICLE 5. Restoration of marine ecosystems

5.5. Member States shall put in place restoration measures for the marine habitats of species listed in Annex III to this Regulation and in Annexes II, IV and V to Directive 92/43/EEC and for the marine habitats of wild birds falling within the scope of Directive 2009/147/EC that are, in addition to the restoration measures referred to in paragraphs 1 and 2 of this Article, necessary to improve the quality and quantity of those habitats, including by re-establishing them, and ***to enhance connectivity****, until sufficient quality and quantity of those habitats is achieved.*

5.8. The restoration measures referred to in paragraphs 1 and 2 shall ***consider the need for improved ecological coherence and connectivity between the habitat types*** *listed in Annex II and take into account the ecological requirements of the species referred to in paragraph 5 that occur in those habitat types.*

BOX 2. References to the need to improve connectivity in the EU Nature Restoration Regulation.

Overall, the European Commission has been encouraging a more integrated and coordinated approach when implementing legislation related to freshwater and marine environments, following a "source-to-sea approach". This could be supported by the Action Platform for Source-to-Sea Management, a stakeholder platform to strengthen benefits across the entire system (**S2S Platform**). This approach may be further enhanced through the recently adopted NRR, which recognises the importance of connectivity to develop well-connected protected and conserved areas among all the different ecosystems. Furthermore, the **EU Adaptation Strategy**, which promotes Nature-based Solutions to reduce climate-induced risks and enhance ecosystem resilience, particularly in relation to food provision, air and water purification, flood protection, biodiversity, and climate mitigation (European Commission, 2021).

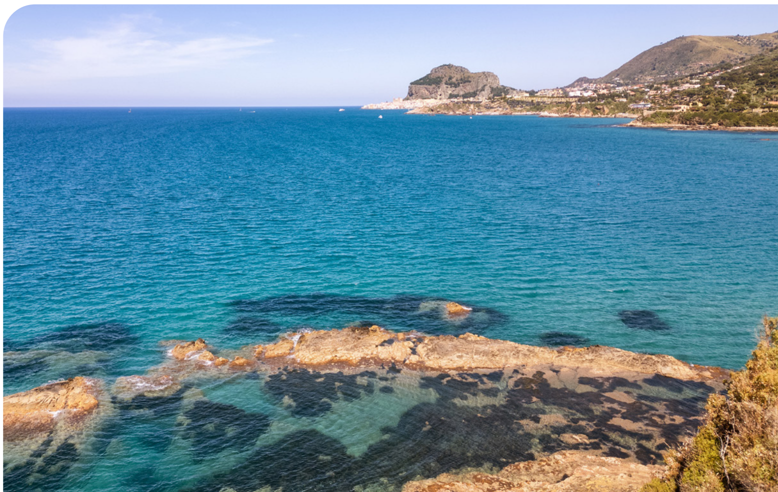
4 Restoring coastal connectivity – contributions from hands-on implementations

The complexity of connectivity, particularly in quantifying and measuring its role in supporting habitats and species, often limits its integration into conservation planning and decision-making. This is especially true in coastal and marine systems, where inherent openness and temporal and spatial variability make connectivity difficult to assess and its ecological impacts harder to predict. Nonetheless, connectivity has been gaining traction in environmental policy for its key contributions to ecosystem functioning and resilience. Coastal ecosystems stand to benefit from further consideration of connectivity in key decision-making processes such as nature restoration efforts, spatial planning, and designation and management of protected areas.

Prioritising coastal connectivity in conservation can help identify where, what, how, and at what scale restoration should occur to build well-connected habitats and reduce fragmentation. A connectivity-focused approach may enhance restoration effectiveness by identifying priority areas and key characteristics necessary to sustain ecosystem functioning and biodiversity. When addressing coastal connectivity, restoration activities may take various forms depending on the type of habitat and its functions, existing barriers, conservation aims, species needs, and institutional context (Hilty *et al*., 2006). Scale is often the most determining factor for the design and implementation of restoration activities. For instance, while large-scale actions may be needed to support species migrations, smaller-scale efforts can restore essential processes like pollination or seed dispersal by submerged plants in fragmented landscapes. Furthermore, connectivity considerations may help strengthen resilience across the land-sea continuum and mitigate climate change impacts on vulnerable coastal ecosystems and the broader ecoscapes that rely on them as transitional areas.

The REST-COAST project showcases a variety of practical methods for restoring coastal connectivity in different ecological, socio-economic and governance settings across Europe and the Mediterranean, through nine Pilot Sites. Despite not all Pilots implementing measures to address the connectivity issues, several of them provide valuable insights into how the integration of coastal connectivity can enhance conservation outcomes, their cost-effectiveness through targeted action, and take account of the social-economic context and targeted spatial planning. The innovative restoration techniques tested and applied within the scope of the REST-COAST project are targeting key aspects of coastal connectivity, such as ecological, hydrological, sediment, and cross-realm connectivity. Additionally, the Pilot Sites also address the broader dimensions of connectivity by strengthening governance frameworks through improved coordination across sectors, institutions, and jurisdictions, enhancing stakeholder engagement to develop solutions suited for the local context and increasing the possibility for long-term support for the restoration initiatives, for instance by improving economic benefits through ecosystem services restoration that maybe be supported by enhanced connectivity (e.g., fisheries). Additionally, the project also emphasises the importance of cross-border collaboration, where aligned policies and joint action can increase the effectiveness of restoration measures related to connectivity.

Based on these results, several **recommendations** have been identified to ensure that coastal connectivity is given due consideration in restoration initiatives, spatial planning, and relevant international and European policy frameworks. The aim is to enhance and inspire the upscaling and outscaling of coastal restoration across Europe and beyond.



UNIFIED APPROACH TO COASTAL CONNECTIVITY

Consider developing clear guidance on how to incorporate a shared operational definition of coastal connectivity into spatial planning and relevant strategies and initiatives at EU and national levels (incl. restoration, such as the NRR). Building on existing work, this definition could benefit from scientific research and practical insights from projects like REST-COAST. It will be important to base the definition on the various conceptualisations found in the relevant disciplines (incl. marine ecology, environmental sciences, and coastal engineering). Following this, the integration of key dimensions of coastal connectivity, including the hydrological, physical, and chemical processes that determine the functioning and composition of coastal ecosystems, as well as their role as transitional zones, would be important. The guidance principles could also indicate the relevant considerations for different contexts in planning and policy instruments. These considerations could include habitat types and functions, species needs, existing barriers, restoration objectives, conservation aims, and the institutional context.

The REST-COAST project provides evidence-based insights into coastal ecosystem restoration. The project's Pilot Sites demonstrate that integrating coastal connectivity, such as habitat networks, hydrological flows, sediment transport and upstream conditions, enhances both ecological and socio-economic outcomes. The application of innovative restoration measures across Pilots, including coastal vegetation restoration (e.g., Arcachon Bay, Venice Lagoon, Foros Bay, Rhône Delta, Wadden Sea), hydraulic dredging (e.g., Ebro Delta, Wadden Sea, Sicily Lagoon), barrier removal (e.g., Ebro Delta, Nahal Dalia, Rhône Delta), construction of sedimentation basins and secondary channels (e.g., Foros Bay, Sicily Lagoon) or artificial islands (Sicily Lagoon), provide valuable context-specific insights for scalable options to guide planning and policies to enhance coastal connectivity and improve conservation outcomes.

STRATEGIC SPATIAL PLANNING

When planning restoration, consider prioritising areas where improving connectivity will have the greatest impact on conservation outcomes. This targeted approach can improve the cost-effectiveness of restoration interventions, increase the value of ecosystem services for local communities and stakeholders, and strengthen the prospect of long-term support. Incorporating connectivity into restoration planning can help inform key decisions, such as where, what, how, and at what scale restoration should be implemented. This effective planning can be achieved by identifying key species, conditions, processes or ecosystem functions to be restored, the required type of connectivity (structural or functional), and the relevant spatial dimensions (longitudinal, lateral or vertical, or even cross-realm). Importantly, the scale of intervention should align with conservation objectives. For instance, large-scale actions may be needed for migratory species or hydrological flows, while smaller-scale efforts may be sufficient to address species-specific processes such as pollination or seed dispersal by submerged plants. It would also be relevant to assess potential trade-offs associated with connectivity. This includes the risk of facilitating the spread of threats, such as invasive alien species, pollution and nutrient surplus, as well as potential trade-offs with other conservation initiatives, which can help to further refine restoration strategies.

The REST-COAST project provides evidence that integrating coastal connectivity into restoration planning and implementation is essential for achieving meaningful and lasting outcomes. By taking this approach, restoration efforts can be better located within the right social and ecological context, re-establish key processes that underpin ecosystem functioning, and address conditions across the entire land-sea continuum – all while respecting local interests and priorities. For instance, strategic hydraulic dredging and barrier removals in the Ebro Delta and Nahal Dalia were designed to restore hydrological and sediment connectivity from river systems to coastal zones. In the Sicily lagoon, the targeted placement of artificial islands supports breeding and nursery grounds for birds and fish. Similarly, large-scale restoration of vegetation in Arcachon Bay and Foros Bay aims to enhance overall ecosystem functioning. In the Wadden Sea, restoration efforts are expected to improve sediment and nutrient trapping, further supporting ecological resilience.

POLICY AND GOVERNANCE COHERENCE

To support effective restoration of coastal ecosystems, stronger institutional coordination among sectors, agencies, and stakeholders would be beneficial. Coastal connectivity is often overlooked due to fragmented governance, where actors operate within their own mandates (e.g., water management, marine conservation, coastal development, agriculture), with limited cross-sector collaboration mechanisms available. This is compounded by technical gaps, such as insufficient data on threat propagation or off-site impacts that cover the whole of land-sea interactions. Addressing these challenges requires coordinated objectives, shared resources, integrated planning and joint efforts among these different actors. Embedding coastal connectivity into relevant mandates and coordination mechanisms – for which the EU NRR presents a key opportunity – can help to ensure more coherent, targeted, and successful restoration outcomes. Synergies between relevant EU policies (MSFD, WFD, NRR, Birds and Habitats Directive) and multilateral environmental agreements (Ramsar Convention, GBF, UNFCCC) must also be further explored and enhanced. International conventions are particularly relevant for countries outside the EU, as is the case for Nahal Dalia in Israel.

As well as testing innovative restoration methods, the REST-COAST project aims to contribute to the development of governance and policy transformations that enable the upscaling and outscaling of coastal restoration initiatives. A good example of this is the establishment of CORE-PLATs (COastal REstoration PLATforms), which bring together public authorities, researchers, NGOs and local stakeholders for each site, to co-design restoration strategies, coordinate actions, build capacity and promote the benefits of coastal ecosystem restoration. In the Ebro Delta, for instance, the CORE-PLATs have helped to facilitate a close collaboration with key governance agencies to discuss a new operational management in the area in support of the restoration initiative's planned actions. In the Sicily Lagoon, the CORE-PLAT helped to overcome some of the institutional barriers and engage local stakeholders in restoration activities, in the Arcachon Bay, it helped facilitate the dissemination and support of upscaling restoration scenarios among local authorities and stakeholders. The CORE-PLATs of the Rhône Delta and the Sicily Lagoon also support monitoring networks tracking various indicators identified for assessing restoration effectiveness.

CROSS-BORDER COOPERATION

As coastal and marine ecosystems often extend beyond administrative and national boundaries, cross-border cooperation is essential to ensure coordinated restoration action and long-term maintenance. Collaboration among neighbouring countries can help align restoration actions and policies and, in some cases, avoid duplication efforts and prevent unintended negative impacts. A useful approach is to develop joint management plans that take into account the entire source-to-sea continuum. Other helpful approaches include cross-border planning bodies, multi-stakeholder platforms, coordinated funding mechanisms, and harmonising legal and regulatory frameworks. Enhancing transboundary collaboration is particularly important for upscaling and outscaling restoration initiatives and ensuring the long-term resilience of coastal ecosystems in the face of climate change and other human-related pressures.

Two REST-COAST Pilot Sites implement restoration activities in coastal ecosystems that cover more than one jurisdiction. The Ems-Dollard estuary, as part of the Wadden Sea, is a great example of how cross-border cooperation can facilitate large-scale restoration and increase restoration effectiveness across the Dutch-German border. This collaboration demonstrates the importance of joint management plans, harmonised policies and shared funding mechanisms in aligning restoration objectives and preventing counterproductive efforts across borders.

METRICS AND INDICATORS

It would be helpful to operationalise robust indicators that capture the key structural and functional aspects of ecosystems, with particular attention to the dynamic nature of coastal ecosystems situated between land and sea. These indicators could encompass key processes and functions, including species dispersal, hydrological and sediment flows, and nutrient cycling, while accounting for temporal variability and other fluctuating environmental conditions. Developing accurate, context-specific metrics is essential for evaluating the effectiveness of restoration efforts, facilitating comparisons across initiatives, and tracking progress made toward national, regional, or global environmental objectives. For instance, these could be used to further track the progress made on connectivity for marine and coastal ecosystems under the GBF, NRR, WFD or MSFD.

Various indicators are used across the REST-COAST Pilot Sites to assess the restoration of coastal connectivity and its impact on the composition and functioning of these ecosystems. In Nahal Dalia, for example, fish surveys are used to track upstream migration as an indicator of improved hydrological connectivity. In the Wadden Sea, turbidity, nutrient levels, fish populations, and soil carbon stocks are being monitored. In Arcachon Bay, various metrics are being used to assess sediment dynamics in relation to seagrass meadows. In Rhône Delta different indicators are being used to understand the chemical characteristics and changes in the area. While these indicators are tailored to the specific goals and environmental dynamics of each site, they could provide valuable guidance on indicators to be used in EU and international policies and regulatory frameworks.

ADAPTIVE MANAGEMENT FOR CLIMATE RESILIENCE

Coastal connectivity plays an important role in ecosystem resilience to climate change. By supporting key ecological processes, it enables species and habitat networks to cope with climate change. For example, enhanced connectivity facilitates species movement and natural coastal defences, as well as limiting sediment and nutrient runoff, contributing to greater resilience in the face of climate-induced stressors such as extreme weather events and fluctuating environmental conditions. Given these benefits, it would be important to incorporate the potential positive contributions of improved coastal connectivity into climate scenario prediction models. To leverage on this, the role of coastal connectivity should be explicitly recognised in key climate adaptation policies, including National Adaptation Plans, National Restoration Plans, and in the forthcoming EU Water Resilience Initiative. Integrating connectivity-focused restoration measures as a NbS, guided by the IUCN **Global Standard for Nature-based Solutions**, can complement or reduce reliance on hard infrastructure, offering more sustainable and adaptive responses to climate-related impacts.

The REST-COAST project provides insights on how restoring coastal connectivity can improve the resilience of coastal ecosystems by enhancing recovery of coastal vegetation, and therefore improving natural defences, reducing coastal erosion and supporting species migration across the land-sea continuum. For instance, in Arcachon Bay, seagrass meadow restoration supports natural coastal defence against erosion and storm surges through sediment trapping, while in the Venice Lagoon similar results are expected in the area from saltmarsh restoration. In the Ebro Delta, restoring sediment flow helps counteract land loss and sea-level rise, while the restoration of the Sicily Lagoon includes adaptive infrastructure (e.g., adjustable water level barriers) that can support limiting the impacts of climate change. These Pilot Sites show how improving coastal connectivity and coastal vegetation can enhance ecological resilience while reducing reliance on hard infrastructure.

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Further policy insights from RESTCOAST

POLICY BRIEF

EU Nature Restoration Regulation and REST-COAST: Setting the Basis for Coastal Restoration

POLICY BRIEF

Unlocking the potential of coastal restoration to strengthen climate action: Opportunities for the Nationally Determined Contributions