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i Executive summary

The Workshop on Nature Restoration and Recovery (WKREST) aimed to enhance understanding of restoration processes, success criteria, and the factors affecting recovery rates in line with international and national policy and legal frameworks. Participants reviewed available methods to model and measure the recovery rate and recovery times of marine habitats and species, and the ecosystem functions they provide (food webs, biodiversity, productivity and habitat provision) relevant to active and passive restoration initiatives. A wide range of ecosystem components, including fish, marine mammals, benthos, and birds, as well as the physical conditions that influence restoration outcomes, such as eutrophication, were examined, and the important role of connectivity in site selection and recovery were reviewed.

WKREST noted that restoration timelines often exceed policy evaluation periods, creating challenges in demonstrating success. Furthermore, the importance of identifying baselines and target measure for success in restoration activities needs to be clearly formulated to be able to achieve success. Recovery rates vary widely among species and habitats, and monitoring programs must align with key habitat features and species life histories. Predictive modelling remains the most practical tool for assessing recovery at habitat and ecosystem scales, but mechanistic models are needed to capture dynamic environmental interactions and future changes, such as climate impacts and species interactions. Connectivity between local sites and the wider landscape is essential for successful restoration, and cooperation between neighbouring jurisdictions is critical, especially in transboundary areas. Significant knowledge gaps persist in understanding species dispersal and connectivity networks, particularly with respect to life-history traits.

ICES can play a role in advancing marine restoration by enhancing knowledge on species recovery rates and ecological connectivity, particularly in offshore areas. Continued development of ICES databases and data visualization tools will improve ecosystem science and management advice. Strengthening international collaboration and integrating diverse datasets will be key to promoting effective and sustainable restoration practices.

ii Expert group information

Expert group name	Workshop on Nature Restoration and Recovery (WKREST)
Expert group cycle	Annual
Year cycle started	2025
Reporting year in cycle	1/1
Chair(s)	Ellen Kenchington, Canada
	Daniël van Denderen, Denmark
	Jan Hiddink, UK
Meeting venue(s) and dates	4-7 March 2025, ICES HQ, Copenhagen, Denmark, (50 participants)

1 Background

The workshop on Nature Restoration and Recovery (WKREST) met between 4-7 March 2025 in ICES HQ, Copenhagen, Denmark and online, chaired by Ellen Kenchington (Canada), Daniël van Denderen (Denmark) and Jan Hiddink (UK). The workshop met with the following terms of reference (the full workshop resolution is available in Annex 2):

a) Summarise available methods (including strengths and weaknesses) to model predictions of recovery times of marine habitats and species, the parameters and data required to apply these methods, and describe additional evidence needs to predict the effects of management measures intended to achieve restoration. The workshop will engage as wide as possible representation of ecosystem components i.e. fish, marine mammals, benthos, birds, etc. as well as considering "ecosystems" as a whole such as trophic interactions (i.e. eutrophication in the Baltic and Black Sea).

b) Summarise available methods to monitor and assess the rate of recovery of marine habitats and species, the resources required to apply these methods, the scales of implementation and their statistical power to detect recovery on defined timescales. Identify additional evidence needs to guide effective monitoring and assessment of the effects of management measures intended to achieve restoration.

c) Review and report on available methods to quantify habitat connectivity, and to monitor and assess changes in connectivity, with a focus on benthic species and habitats of the continental shelves and deep-sea. Report on the implications of habitat connectivity for recovery rates and restoration, and priority evidence needs.

d) Report on the ways in which existing data streams/ calls and methods adopted by the ICES Data Center and expert groups may contribute to meeting evidence needs and priorities identified in ToR a-d.

e) Summarise available and proposed measures and potential threats to achieving the active restoration of marine habitats, their state of development (e.g. from experimental to large-scale trials and applications), relative benefits and costs, and effectiveness. Identify additional evidence needs to evaluate the costs and benefits of active restoration.

f) Review the current use of ecological restoration objectives in marine management and policy and identify the set targets.

The report is structured in such a way as to make it readable as a report rather than organized by the terms of reference (ToRs). It contains an introduction, an overview of the policy setting (ToR f), a summary of the available methods to model and measure the recovery rate and recovery times of marine habitats and species (ToR a, ToR b), a review of the available methods to quantify habitat connectivity, and to monitor and assess changes in connectivity (ToR c), a summary of available and proposed measures and potential threats to achieving the active restoration of marine habitats and their state of development (ToR e), a description of the ways in which existing data streams/ calls and methods adopted by the ICES Data Center and ICES expert groups may contribute to meeting evidence needs and priorities identified in the report (ToR d), and concludes with some suggestions for short-, medium-, and long-term science priorities that would help inform nature restoration activities. For each relevant section of the report we provide 'key messages' to take away from the text.

2 Glossary of Terms with Different Legal and/or Policy and/or Guidance Documents' Definitions and Objectives

Nature restoration in a general context can be defined as an action that re-establishes/restores natural habitats, hydrological processes, biological mechanisms and/or populations where they have been lost or degraded. In this section we highlight different definitions for ecosystem restoration and degradation contained in legal and/or policy instruments, and/or in specific guidance documents, in order to facilitate a common understanding for the readership of this report.

2.1 Ecosystem Restoration

Convention on Biological Diversity (CBD): "the process of managing or assisting the recovery of an ecosystem that has been degraded, damaged or destroyed as a means of sustaining ecosystem resilience and conserving biodiversity. Degradation is characterized by a decline or loss of biodiversity or ecosystem functions. Degradation and restoration are context-specific and refer to both the state of ecosystems and to ecosystem processes" (CBD decision XIII/5 (2016), Annex, para. 4).

"Ensure urgent management actions to halt human induced extinction of known threatened species and for the **recovery and conservation of species**, in particular threatened species, to significantly reduce extinction risk, **as well as maintain and restore the genetic diversity within and between populations of native, wild and domesticated species to maintain their adaptive potential**, including through in situ and ex situ conservation and sustainable management practices, and effectively manage human-wildlife interactions to minimize human-wildlife conflict for coexistence." (CBD decision 15/4 (2022), Annex, Target 4, emphasis added).

UN Environment Programme (UNEP): "the process of halting and reversing degradation, resulting in improved ecosystem services and recovered biodiversity. Ecosystem restoration encompasses a wide continuum of practices, depending on local conditions and societal choice" (UNEP, 2021, p. 7).

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES): "Any intentional activity that initiates or accelerates the recovery of an ecosystem from a degraded state. Active restoration includes a range of human interventions aimed at influencing and accelerating natural successional processes to recover biodiversity ecosystem service provision. Passive restoration includes reliance primarily on natural process of ecological succession to restore degraded ecosystems but may include measures to protect a site from processes that currently prevent natural recovery (e.g. protection of degraded forests from overgrazing by livestock or unintentional human-induced fire)." (IPBES, 2018).

United Nations Convention on the Law of the Sea (UNCLOS): "such measures shall be designed to maintain or **restore** populations of harvested species at levels which can produce the **maximum sustainable yield [MSY],** as qualified by relevant environmental and economic factors, including the economic needs of coastal fishing communities and the special requirements of developing States, and taking into account fishing patterns, the interdependence of stocks and any generally recommended international minimum standards, whether subregional, regional or global" (UNCLOS, 1982; Art. 61 (3), emphasis added).

RAMSAR Convention on Wetlands: "projects that promote a return to original conditions and projects that improve wetland functions without necessarily promoting a return to pre-disturbance conditions" (Ramsar Convention resolution VIII.16 (2002), para. 3).

EU Nature Restoration Law: "the process of actively or passively assisting the recovery of an ecosystem in order to improve its structure and functions, with the aim of conserving or enhancing biodiversity and ecosystem resilience, through improving an area of a habitat type to good condition, re-establishing favourable reference area, and improving a habitat of a species to sufficient quality and quantity in accordance with Article 4(1), (2) and (3) and Article 5(1), (2) and (3), and meeting the targets and fulfilling the obligations under Articles 8 to 12, including reaching satisfactory levels for the indicators referred to in Articles 8 to 12" (EU Regulation 2024/1991, Art. 3(3)).

2.2 Ecosystem Degradation

Food and Agriculture Organization of the United Nations (FAO) (Nelson et al., 2024 guidelines): Defines ecosystem degradation as the inverse of ecosystem integrity. Ecosystem integrity is defined as the degree to which an ecosystem's physical condition, composition, structure and function are intact.

CBD Short Term Action Plan on Ecosystem Restoration (STAPER): Degradation is characterized by a decline or loss of biodiversity or ecosystem functions. Degradation and restoration are context-specific and refer to both the state of ecosystems and to ecosystem processes (CBD decision XIII/5, Art. 4).

System of Environmental Economic Accounting, Ecosystem Accounting (SEEA-EA) (2021): The decrease in the value of an ecosystem asset over an accounting period that is associated with a decline in the condition of an ecosystem asset during that accounting period (ST/ESA/STAT/SER.F/124 para. A.10.21).

UN Decade on Ecosystem Restoration, Standards of Practice to Guide Ecosystem Restoration (SOPs): "A persistent deterioration of ecosystem attributes (e.g., abiotic condition, species composition, ecosystem structure and function, external exchanges) relative to reference conditions, due to direct (e.g., unsustainable resource use, land use change, overexploitation, contamination) or indirect (e.g., climate change) human intervention, that affects the ecosystem's capacity to provide benefits to people and nature" (United Nations Environment Programme (UNEP), and Food and Agriculture Organization of the United Nations (FAO), 2020).

3 Introduction to Restoration

Ecosystem restoration can be seen as a continuum (Figure 3.1), and this concept is the foundation to the UN Decade on Ecosystem Restoration. Restoration activities aim for a wide range of impacts, from reducing societal impacts to fully restoring native ecosystems. Restoration can proceed through passive restoration, active restoration, and rehabilitation, or combinations thereof.

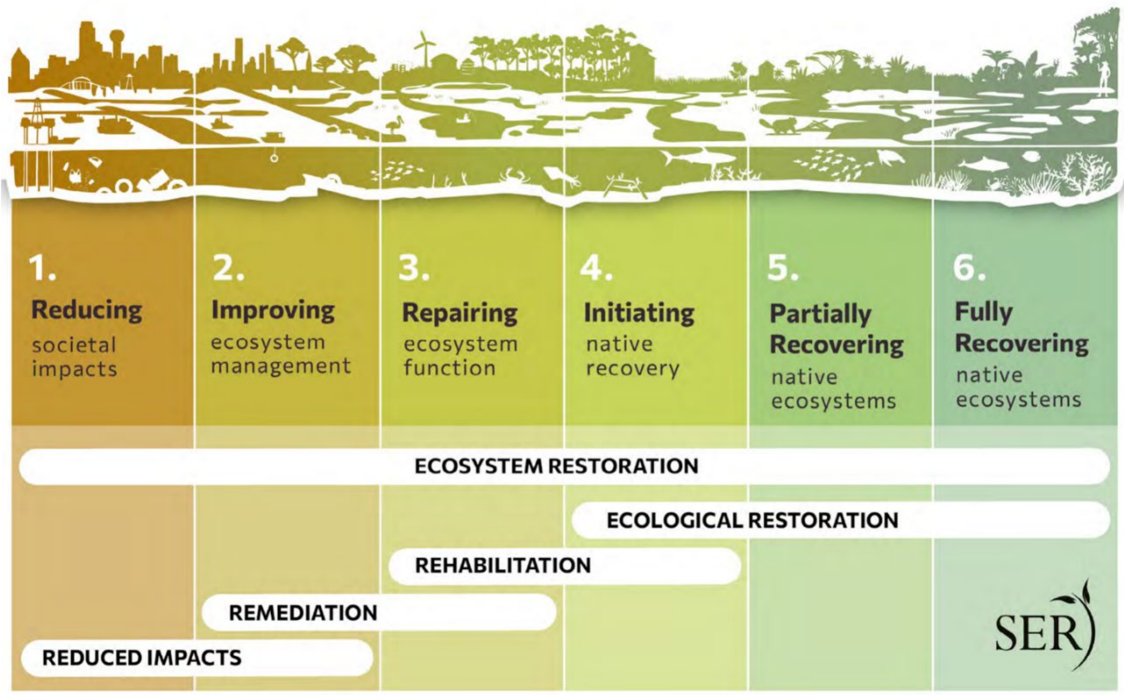

Figure 3.1. The restorative continuum. Source: FAO, SCBD and SER (2024).

Across this continuum, the aim can be for ecosystems to be in natural, productive or transformed states (IPBES, 2019). **Natural ecosystems** exist without significant human intervention and are subject to natural fluctuations. **Productive ecosystems** are managed or modified by humans to maximize resource production (e.g., food, timber, or fish) and are often designed for economic benefit while maintaining some ecological functions. **Transformed ecosystems** are heavily altered by human activities, often losing most of their original ecological functions and are typically dominated by artificial structures or human development (IPBES, 2019). Climate change challenges the overall concept of natural ecosystems in the twenty-first century. Restoration is required when these ecosystems are considered degraded.

To support the implementation and achievement of restoration goals, a shared global vision has been created. This vision for restoration has led to the adoption of ten principles to guide ecosystem restoration (Figure 3.2). These principles underpin the full set of ecosystem restoration activities. These ten principles and associated best practices (FAO, IUCN CEM and SER, 2021; Gann et al., 2019; UNEP and FAO, 2020; Silliman et al., 2023; Nelson et al., 2024) maximize the net gain for native biodiversity, ecosystem health and integrity, and human health and well-being, across all biomes, sectors and regions. Restoration projects and measures should take into account the ecological, cultural and socioeconomic contexts, as well as financial constraints. Restoration targets and indicators should be identified, and with specific restoration goals and objectives developed. A monitoring and evaluation component is necessary that focuses on measuring progress towards the recovery of the restoration targets and achievement of the restoration goals and objectives (Nelson et al., 2024). These recommendations can be applicable across all sectors of society, land or sea uses, ecosystems and regions, and to different ecosystem restoration activities (Nelson et al., 2024).

Figure 3.2 The UN ten principles to guide ecosystem restoration (FAO, IUCN CEM and SER, 2021).

Many of these principles and associated best practices are similar to those underlying ecosystem-based management (Garcia et al., 2003; ICES, 2020a; Haugen et al., 2024) and align with many similar approaches for sustainable ocean governance, e.g., integrated ocean management, the use of tools such as marine spatial planning (Stephenson et al., 2021). It is necessary to reduce pressures that degrade the habitats, species and ecosystem functioning before implementing other measures for restoration.

In the marine environment much work on active restoration has occurred in habitat forming species such as coral reefs, mangroves, seagrass, kelp, and bivalves. Almost none has occurred in open seas and deep oceans other than through passive closures of vulnerable and sensitive habitats (see below). Furthermore, the CBD COP has recognized that marine ecological restoration requires further guidance for the implementation of KM-GBF Target 2 by its Parties and competent organizations (CBD decision 16/17 (2024), Annex). The recovery of over-exploited natural resources could be seen as a component of ecosystem restoration, and the workshop considers that other targets of the GBF (Targets 4, 5 and 10) and fisheries management are the tools to address this challenge. The status and restoration of cod in the Baltic Sea illustrates some of the challenges associated with addressing pressures or degraded habitat. It is probable that due to the degraded state of the Baltic Sea, reducing the main direct anthropogenic pressure on the population (fishing) will not result in recovery or restoration of the species in the Baltic. Suitable habitat must be made available first (Eero et al., 2023).

3.1 Restoration Knowledge

Restoration ecology is the scientific study of restoring degraded, damaged, or extirpated ecosystems through human intervention, and is aimed at recovering their health, ecological integrity, and sustainability. This is typically achieved by reintroducing habitats formed by flora and fauna, or by remediating physical habitats with the goal of halting and reversing degradation and effectively restoring ecosystem functions and services and natural biodiversity (UNEP and FAO, 2020). Since marine ecosystems are currently endangered by multiple threats, including direct and indirect anthropogenic pressures, and ecosystem stress is expected to increase over the next few decades leading to a decline in biodiversity, ecosystem functions and services, ecological restoration is a strategic conservation priority.

3.2 Potential Measures to Bring About Restoration

Passive restoration is the natural recovery of an ecosystem after removing the sources of disturbance or pressure. In the marine realm, passive restoration of benthic habitats may occur in areas closed to bottom-contact fishing gears. For example, in the Mediterranean Sea, the General Fisheries Commission for the Mediterranean (GFCM) has established Fisheries Restricted Areas (FRAs), where specific fishing activities are temporarily or permanently banned or restricted to enhance the conservation of targeted stocks as well as deep-sea benthic habitats. In the context of the Baltic Sea, passive restoration would involve limiting the nutrient loads from land-based catchment areas leading to improved water quality and natural restoration of habitats and ecosystems. With ecologically representative and well-connected networks of marine protected areas (MPAs) and other effective area-based conservation measures (OECMs) integrated into wider seascapes[1] (CBD, 2018) either planned or in place, passive restoration may be the most common restoration approach. This assumes that the areas protect degraded, damaged or extirpated ecosystems and that the source of disturbance is addressed. The European Commission also highlight that protected areas can provide an important contribution to the restoration targets in the EU Biodiversity Strategy for 2030 (European Commission, 2022).

Active restoration is a human-led intervention that initiates or accelerates restoration of an ecosystem, and like passive restoration requires the removal of the sources of disturbance to have the desired effect. Active restoration may involve the addition of structural complexity to recreate lost habitats and/or introduction or removal of species from an area. Active restoration of seagrass meadows is one of the earliest large-scale marine restoration habitat initiatives (Fonesca, 2011; Ward and Beheshti, 2023), and on the eastern seaboard of the USA, over 70 million seeds of eelgrass (*Zostera marina*), have been broadcast into mid-western Atlantic coastal lagoons, leading to recovery of 3612 ha of seagrass meadows (Orth et al., 2020). Oyster reef restoration has also been successful and has expanded from the USA to other areas such as Australia, New Zealand, Europe, and Asia (Fitzsimons et al., 2020; Howie and Bishop, 2021). As oysters require a

[1] Seascapes are "large, multiple-use marine areas, defined scientifically and strategically, in which government authorities, private organizations, and other stakeholders cooperate to conserve the diversity and abundance of marine life and to promote human well-being" (Atkinson et al., 2011).

shell base for spat settlement and reef accretion, oyster reef restoration often includes substrate addition in the form of oyster shells or other hard substrates (Howie and Bishop, 2021). Restoration of macroalgal forests through addition of lost hard substrate requires addition of boulders to areas (Støttrup et al., 2017). Removal of invasive species from an area to facilitate the recovery of other species can be less successful in open systems, but there are some examples where it has been successful. A well-known example is the response to major invasions of the Indo-Pacific red lionfish (*Pterois volitans* and *P. miles*) into the Atlantic and Mediterranean, which have been locally suppressed by spearfishing and other removal methods (Davis et al., 2021; Ulman et al., 2022). Another example is the culling of local jellyfish blooms to enhance other types of zooplankton and small-pelagic fish (Gibbons et al., 2015).

Ecosystem rehabilitation involves restoration through the reparation of ecosystem processes, productivity and services, but without re-establishing the pre-existing species composition and structure (UN-REDD Programme, 2025). Therefore, on its own, ecosystem rehabilitation does not aspire to restore ecosystems, however it can be an *essential* component of ecosystem restoration. Rehabilitation methods were widely used in the 21st century, with chemical remediation, i.e., removal of pollutants, the most applied approach in Europe (Oliveira et al., 2024). Restoration attempts to return an ecosystem to its original state, while rehabilitation acknowledges that the ecosystem may be permanently altered and seeks to partially or fully repair the capacity of ecosystems to provide functions and services. Restoration, whether active or passive, cannot proceed if the physical/chemical environment is not also rehabilitated, enabling ecosystem restoration. We provide further examples of well-designed restoration activities in Section 7 (ToR E) where we also discuss why some projects have been successful while others have not.

3.3 Policy Setting

After failing to meet the Aichi Targets (CBD decision X/2 (2010)), the CBD Conference of the Parties (COP) adopted the Global Biodiversity Framework (GBF) to guide conservation efforts by 2030 through specific targets, in the context of ultimate conservation, sustainable use and equity goals to be achieved by 2050 (CBD decision 15/4 (2022)). Target 2 of the GBF supersedes the previous Aichi Biodiversity Target 15, focusing on ecosystem restoration, and calling for at least 30% of all degraded ecosystems to be "under effective restoration" (CBD, 2022, Annex, Target 2; See Text Box 1). In 2024, the European Union (EU) adopted a Nature Restoration Regulation (NRR) on ecosystem restoration, which is a key element of the EU Biodiversity Strategy (Text Box 2) (European Union, 2024; Regulation 2024/1991). This law is a key instrument to support the EU and its Member States in meeting their international biodiversity commitments under the GBF. All other ICES member countries, except the USA are parties to CBD, and are expected to meet the political commitments of the GBF. These various instruments are further discussed, especially in relation to restoration targets and objectives, in Section 4 of this report.

Text Box 1: GBF Target 2

Restore 30% of all Degraded Ecosystems

Ensure that by 2030 at least 30 percent of areas of degraded terrestrial, inland water, and coastal and marine ecosystems are under effective restoration, in order to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity.

Text Box 2. EU Nature Restoration Law Article 5

Restoration of marine ecosystems

1. Member States shall put in place the restoration measures that are necessary to improve to good condition areas of habitat types listed in Annex II which are not in good condition. Such restoration measures shall be put in place:

(a) by 2030, on at least 30 % of the total area of groups 1 to 6 of the habitat types listed in Annex II that is not in good condition, as quantified in the national restoration plan referred to in Article 15;

(b) by 2040, on at least 60 % and, by 2050, on at least 90 % of the area of each of the groups 1 to 6 of the habitat types listed in Annex II that is not in good condition, as quantified in the national restoration plan referred to in Article 15;

(c) by 2040, on at least two thirds of the percentage referred to in point (d) of this paragraph of the area of group 7 of the habitat types listed in Annex II that is not in good condition, as quantified in the national restoration plan referred to in Article 15; and

(d) by 2050, on a percentage, identified in accordance with Article 14(3), of the area of group 7 of the habitat types listed in Annex II that is not in good condition, as quantified in the national restoration plan referred to in Article 15.

This report provides an overview of the available methods (including strengths and weaknesses) to **model predictions of recovery times** of marine habitats and species, the parameters and data required to apply these methods, and **describe additional evidence needs** to predict the effects of management measures intended to achieve restoration (Section 5; ToR a). Additionally, the structure and function of marine ecosystems respond drastically to inter-annual changes and inter-decadal **climatic variations**, and so historical baselines were reviewed to understand the scope of natural variability when predicting recovery times. WKREST uses this information:

1) to **contextualize** what species, habitats and ecosystems may reach a recovered state within the policy and legal timelines imposed, and discuss the uncertainty associated with the prediction of recovery times;
2) to **consider** what methods are most appropriate to assess recovery for a wide range of ecosystem components, i.e. fish, marine mammals, benthos, birds, etc. We apply a similar approach to the methods available to effectively monitor and assess the rate of recovery of marine habitats and species (Section 5; ToR B);
3) and to **discuss** the available methods to quantify habitat connectivity, and to monitor and assess changes in connectivity, with a focus on benthic species and habitats of the continental shelves and deep-sea. The implications of habitat connectivity site selection, for recovery rates and restoration, and priority evidence needs will be documented (Section 6; ToR C).

ICES (2019) in a report summarizing the more general functional aspects of the Barents Sea identified four general ecological dimensions that are not explicitly discussed in currently published restoration guidelines and that warrant consideration when restoring ecosystem functioning and services. Further, they relate to a number of policy objectives in international fora (Section 4 and Table 4.2): food web, habitat, biodiversity, and productivity. These dimensions could be considered when monitoring ecosystem function. The dimensions have been redescribed here in the context of ecosystem restoration:

1) Food web: The integrity of the food web is key to maintaining ecosystem structure and function. From a practical perspective this means identifying and safeguarding those biological/ecological components that play major roles in the transfer of energy across trophic levels;
2) Habitat: The quality of physical habitat (benthic and pelagic) and of biogenic/complex habitats;
3) Biodiversity: "Biological diversity" means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (CBD, 1992);
4) Productivity: Primary/secondary production, and the species concentrating biomass.

We propose to consider these dimensions in our methodological overviews where applicable (Sections 5).

4 Restoration Objectives in Marine Policy and Management

This section corresponds to WKREST ToR f) Review the current use of ecological restoration objectives in marine management and policy and identify the set targets.

Key Messages

- Marine ecosystem restoration has increasingly become a prominent feature in several policy and legal instruments across different governance scales.
- Definitions of terms related to restoration and timeframes for achieving restoration outcomes vary across different policy and legal frameworks and more clarity would be helpful in moving forward.
- Several questions remain in the operationalization of policy and legal targets and objectives, including around baselines (and shifting baselines), desired ecological condition, and spatial scales.
- At the same time, there is consistency in these frameworks in highlighting essential components of effective restoration for restoring ecosystem integrity (structure and functioning). These include: habitat, biodiversity, productivity, food webs, and connectivity. Resilience has been highlighted in some of them.
- Policy coherence is needed to help operationalize ecosystem restoration objectives. In the EU context, the EU Nature Restoration Regulation attempts to achieve such coherence, but it is still at early stages of implementation.
- It is essential to identify the commonalities and differences among various policy objectives and restoration targets to ensure effective and coherent conservation efforts.

International and national policy and legal frameworks provide targets and/or objectives around ecosystem restoration. This section details the relevant restoration objectives and targets included in relevant international frameworks from 2010 to 2025, clarifying the relevant terms and approaches. This section discusses how the different instruments can lead to policy coherence especially when considering supplementary technical guidance around the ecosystem approach, understanding species interactions, high-impact biodiversity areas, life-history stages, endangered or threatened species, biological productivity, and ecological connectivity and integrity as well as resilience. This guidance can assist in project prioritization, stakeholder engagement, and eventual success of restoration projects.

Ecosystem restoration, including in marine and coastal areas, has been gaining increasing impetus in international and national policy and legal frameworks in recent years. The Sustainable Development Goal (SDG) 14.2 called upon States to "By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by **strengthening their resilience**, and take action for their **restoration** in order to achieve **healthy and productive oceans**" (UNGA resolution 70/1 (2015), emphasis added). In assessing progress towards the achievement of this target, the 2024 UN report on the SDGs noted that there has been marginal progress, and significant acceleration is needed (United Nations, 2024).

In 2019 the United Nations General Assembly (UNGA) declared the decade of 2021-2030 as a UN Decade on Ecosystem Restoration, which aims to recover degraded or destroyed ecosystems, as well as to conserve the ecosystems that are still intact (UNGA resolution 73/284 (2019)). As a result, the United Nations Environment Programme (UNEP), the Food and Agriculture Organization of the UN (FAO), the International Union for the Conservation of Nature (IUCN), among other organisations have developed several guidance documents to support the implementation of the Decade. For instance, **UNEP has defined ecosystem restoration** as "the process of halting and reversing degradation, resulting in improved ecosystem services and recovered biodiversity. Ecosystem restoration encompasses a wide continuum of practices, depending on local conditions and societal choice" (UNEP, 2021, p. 7). FAO, IUCN, and the Society for Ecological Restoration (SER) have developed ten principles to guide ecosystem restoration under the Decade (FAO, IUCN, and SER, 2021). These principles are based on the ecosystem approach and the Short Term Action Plan for Ecosystem Restoration under the CBD (see subsection A below), among other instruments and documents (FAO, IUCN, and SER, 2021). The principles are applicable to all sectors, biomes and regions (see figure 3.2). Following the publication of the ten principles, a document entitled Standards of Practice to Guide Ecosystem Restoration was published by FAO and others (Nelson et al., 2024). Although not policy instruments per se, these principles and standards can guide good practices in marine restoration activities.

Interestingly, the same decade of 2021-2030 was also declared as the UN Decade of Ocean Science for Sustainable Development (UNGA resolution 72/73 (2017)). Within the UN Ocean Science Decade, the need to protect and restore ecosystems and biodiversity has been highlighted among the goals of its Challenge 2 which was specifically conceived with the aim to understand the effects of multiple stressors on ocean ecosystems, and develop solutions to monitor, protect, manage and restore ecosystems and their biodiversity under changing environmental, social and climate conditions (Muller-Karger et al., 2024).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has defined restoration as:

"Any intentional activity that initiates or accelerates the recovery of an ecosystem from a degraded state. Active restoration includes a range of human interventions aimed at influencing and accelerating natural successional processes to recover biodiversity ecosystem service provision. Passive restoration includes reliance primarily on natural process of ecological succession to restore degraded ecosystems, but may include measures to protect a site from processes that currently prevent natural recovery (e.g. protection of degraded forests from overgrazing by livestock or unintentional human-induced fire)." (IPBES, 2018).

It is important to note that this definition is contained in the IPBES Land Degradation and Restoration Assessment (2018), which focuses on terrestrial ecosystems – although it refers to wetlands in instances, including coastal ones.

Global biodiversity goals and targets on restoration have also been set and evolved over the past decade (e.g., Target 15 of the CBD Aichi Biodiversity Target (CBD decision X/2 (2010)), which has been replaced by Target 2 of the GBF (CBD decision 15/4 (2022)). **CBD GBF Target 2** commits CBD Parties to: "Ensure that by 2030 at least 30 per cent of areas of degraded terrestrial, inland water, and marine and coastal ecosystems are under **effective restoration**, in order **to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity**." (CBD decision 15/4 (2022), Annex, Target 2, emphasis added) (see Section 4.1 below).

Before discussing this global commitment, it is important to contextualise the restoration discussion in light of key obligations contained in the **United Nations Convention on the Law of the Sea (UNCLOS)** on the protection and preservation of the marine environment. The UNGA has repeatedly affirmed that this "Convention sets out the legal framework within which all activities in the oceans and seas must be carried out and is of strategic importance as the basis for national, regional and global action and cooperation in the marine sector" (UNGA resolution 79/144 (2024), 5th preambular paragraph).

Part XII of UNCLOS (1982) on the protection and preservation of the marine environment sets relevant obligations, including the duty of States to protect and preserve the marine environment (UNCLOS, 1982;Art. 192) both within and beyond national jurisdiction (ITLOS, 2024, para. 400). With respect to this specific obligation, the International Tribunal for the Law of the Sea (ITLOS) has interpreted the term "preservation" as to possibly include "restoration", as follows:

"**Where the marine environment has been degraded**, the Tribunal is of the view that **the term "preservation" may include restoring marine habitats and ecosystems**. The term "restoration" is not used in article 192 of the Convention but flows from the obligation to preserve the marine environment where the process of reversing degraded ecosystems is necessary in order to regain ecological balance." (ITLOS, 2024, para 386, emphasis added).

Another important obligation contained in Part XII of UNCLOS (1982) is to take measures "**necessary to protect and preserve rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life**" (UNCLOS, 1982; Art. 194 (5)). Following the same logic, restoration of such habitats and ecosystems when degraded would therefore be mandatory.

This interpretation from the Tribunal is timely, considering the increased prominence of restoration in the international agenda. Interestingly, the UNCLOS Informal Consultative Process meeting of 2026 will focus on marine ecosystem restoration (UNGA resolution 79/144 (2024), para 347). UNGA resolution 79/144 (2024) on oceans and the law of the sea also noted the vital role that coastal blue carbon ecosystems (e.g., mangroves, tidal marshes, seagrasses) play in climate adaptation and mitigation and encouraged "States and relevant international institutions and organizations to work collaboratively to protect and restore coastal blue carbon ecosystems" (para. 212).

Other international instruments (e.g. Convention on Migratory Species of Wild Animals (CMS), Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention) also address or apply to marine and coastal biodiversity/ecosystem restoration, as discussed in Sections 4.4 and 4.5 below.

Since the adoption of the GBF, relevant legal obligations have been adopted under EU restoration law, and other CBD Parties are also updating their environmental laws and/or policies with a view to integrate restoration goals and targets (e.g., Australia – see Bell-James, 2024). Within the EU, several other instruments complement the recently adopted law, or also alludes to restoration. For instance, under the EU Marine Strategy Framework Directive restoration activities comply with 'Mitigation and remediation tools for restoring damaged components of marine ecosystems' (Directive 2008/56/EC) (see Section 4.6 below). For the purposes of this Section, no other jurisdictions have been considered.

The analysis of the instruments referred to above will particularly focus on objectives, targets and timelines for the restoration of specific habitats, species, ecosystems contained therein (when applicable). For this purpose, these instruments are clustered around the following broad themes: (4.1) biodiversity and ecosystems (focusing on relevant CBD provisions and decisions); (4.2) fisheries context (focusing primarily on relevant provisions of the United Nations Convention on the Law of the Sea (UNCLOS), the UN Fish Stocks Agreement, UNGA Resolutions, and FAO and WTO instruments); (4.3) biodiversity beyond national jurisdiction (briefly reflecting on key provisions of the BBNJ Agreement); (4.4) migratory species (focusing on CMS); (4.5) wetlands (focusing on Ramsar Convention); (4.6) Regional Seas Organisations; (4.7) EU nature restoration law; and (4.8) rights holders and stakeholders involvement. Climate change and ocean acidification will be addressed as a cross-cutting issue in this Section, as appropriate. Finally, some illustrative examples of management interventions in the marine environment are provided in Section (4.9) below. A summary table is presented in the conclusions section with a view to bring together some of the key components and timelines identified among the different international targets applicable to marine and coastal ecosystem restoration.

4.1 Biodiversity & Ecosystem's Restoration Under the CBD

The Convention on Biological Diversity's objectives are the conservation of biodiversity, the sustainable utilisation of its components, and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources (CBD, Art. 1). The Convention sets specific obligations to achieve these objectives. The provisions on in-situ conservation of biodiversity are of particular relevance to ecological restoration. Firstly, in-situ conservation is defined under the Convention as:

"the conservation of ecosystems and natural habitats and the maintenance and **recovery** of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties" (CBD, Art. 2, emphasis added).

Article 8 of the Convention contains specific qualified obligations regarding in-situ conservation, including, among several others, the establishment of a system of (marine) protected areas, and to "**[r]ehabilitate and restore** degraded ecosystems and promote the **recovery** of threatened species, inter alia, through the development and implementation of plans and other management strategies" (CBD, Art. 8(f)).

4.1.1 2010 Aichi Biodiversity Targets on Restoration and 2016 Restoration Action Plan

While the Convention itself did not establish specific **timelines and thresholds** for these obligations to be implemented, CBD Conference of the Parties (COP) has over the years deliberated on these matters. For instance, one of the rationale for the 2011-2020 Strategic Plan for Biodiversity and its Aichi Biodiversity Targets focused on the need to restore biodiversity and ecosystems considering the rate of biodiversity loss due to anthropogenic pressures (CBD decision X/2 (2010), Annex, paras. 7, 10 (c) and (d)). Restoration-related goals of that Strategic Plan included:

(i) Continuing direct action to safeguard and where necessary, restore biodiversity and ecosystem services, including through habitat restoration and species-recovery programmes (CBD decision X/2 (2010), Annex, para. 10 (c)); and

(ii) Efforts to ensure the continued provision of ecosystem services and to ensure access to these services. In relation to this goal, it was recognised, among other things, that ecosystem restoration generally provide cost-effective ways to address climate change (CBD decision X/2 (2010), Annex, para. 10 (d)).

The **2050 Vision** of the Strategic Plan (**which is still in place under the GBF** – as further discussed below in this section) is "a world of "Living in harmony with nature" where "**By 2050, biodiversity** is valued, conserved, **restored** and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people"" (CBD decision X/2 (2010), Annex, para. 11, emphasis added).

The mission of the Strategic Plan was to:

"take effective and urgent action to halt the loss of biodiversity in order to **ensure that by 2020** ecosystems are resilient and continue to provide essential services, thereby securing the planet's variety of life, and contributing to human well-being, and poverty eradication. To ensure this, pressures on biodiversity are reduced, **ecosystems are restored**, biological resources are sustainably used (…) biodiversity issues and values mainstreamed, appropriate policies are effectively implemented, and decision-making is based on sound science and the precautionary approach" (CBD decision X/2 (2010), Annex, para. 12, emphasis added).

Under the 2011-2020 Strategic Plan, two Aichi Biodiversity Targets explicitly referred to restored ecosystems or restoration activities, namely:

- "Target 14: By 2020, **ecosystems that provide essential services**, including services related to water, and contribute to health, livelihoods and well-being, **are restored and safeguarded**, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable" (CBD decision X/2 (2010), Annex, Target 14, emphasis added).
- "Target 15: By 2020, **ecosystem resilience and the contribution of biodiversity to carbon stocks** has been enhanced, through conservation and **restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation** and to combating desertification" (CBD decision X/2 (2010), Annex, Target 15, emphasis added).

The global assessment conducted under the Convention on the achievement of the Aichi Targets (Fifth Global Biodiversity Outlook – GBO-5) concluded that none of the Aichi Targets had been achieved (CBD Secretariat, 2020). Specifically with respect to Target 14, GBO-5 concluded with medium confidence that this target has not been achieved, and noted, inter alia, that "[a]lmost all of the categories relating to the regulation of environmental processes are in decline, suggesting that the capacity of ecosystems to sustain contributions to people are being compromised" (CBD Secretariat, 2020, p.96). The assessment also highlighted the importance of protected areas and other effective area-based conservation measures (OECMs) "for safeguarding ecosystems that provide essential services, and hence potentially play a key role in achieving Target 14" (CBD Secretariat, 2020, p.97).

With respect to Aichi Target 15, GBO-5 concluded with medium confidence that the target was not achieved (CBD Secretariat, 2020), noting that:

"Progress towards the target of restoring 15 per cent of degraded ecosystems by 2020 is limited. Nevertheless, ambitious restoration programmes are under way or proposed in many regions, with the potential to deliver significant gains in ecosystem resilience and preservation of carbon stocks" (CBD Secretariat, 2020, p. 100).

It is important to note, however, that this assessment did not disaggregate marine and terrestrial information in evaluating the achievements under this target. It specifically noted examples of restoration on forests, grasslands, peatlands, mangroves and coral reefs all together. While a lot of emphasis had been on forest ecosystems, one of the studies considered by the GBO-5 assessment focused on 235 marine coastal case studies of restoration or rehabilitation projects of coral reefs, seagrasses, mangroves, saltmarshes, as well as oyster reefs (Bayraktarov et al., 2016). GBO-5 also assessed actions towards the implementation of the **2016 Action Plan for Ecosystem Restoration** adopted under the CBD (CBD decision XIII/5 (2016). The Action Plan **defines 'ecological restoration'** as:

"the process of managing or assisting the recovery of an ecosystem that has been degraded, damaged or destroyed as a means of sustaining ecosystem resilience and conserving biodiversity. Degradation is characterized by a decline or loss of biodiversity or ecosystem functions.

Degradation and restoration are context-specific and refer to both the state of ecosystems and to ecosystem processes" (CBD decision XIII/5 (2016), Annex, para. 4).

In terms of **timeframes**, the Action Plan notes that while the plan provides options for short-term actions, "restoration involves sustained activities over the medium and long term. Therefore, the actions identified in this plan should be undertaken in the context of the 2050 Vision of the Strategic Plan for Biodiversity and the 2030 Agenda for Sustainable Development" (CBD decision XIII/5 (2016). Annex, para. 6).

One of the **principles** of the Action Plan spell out the notion that ecosystem restoration is to complement (and not replace) conservation activities, which should be given priority alongside the prevention of degradation of habitats and ecosystems through the reduction of pressures and through the maintenance of **ecological integrity** (CBD decision XIII/5 (2016), Annex, para. 8). Another principle of the Plan states that **ecosystem restoration should be consistent with the ecosystem approach and its principles as contained in CBD decisions V/6 (2000) and VII/11 (2004)**[2]. In this context, it is important to note principle 5 of the CBD ecosystem approach, which states that **conservation of ecosystem structure and functioning**, to maintain ecosystem services, **should be a priority target of this approach**. The rationale for this principle is that **ecosystem functioning and resilience** depends on a dynamic relationship within species, among species and between species and their abiotic environment, and the physical and chemical interactions within the environment (CBD decision VII/11 (2004), Annex I, Table 1, principle 5). The CBD decision on ecosystem approach also notes that "[t]he conservation and, where appropriate, restoration of these interactions and processes is of greater significance for the long-term maintenance of biological diversity than simply protection of species" (CBD decision VII/11 (2004), Annex I, Table 1, principle 5). In relation to this principle, the CBD ecosystem approach implementation guidelines note that "management must focus on maintaining, and where appropriate restoring, the key structures and ecological processes (e.g., (…) **food webs**) rather than just individual species" (CBD decision VII/11 (2004), Annex I, Table 1, principle 5, emphasis added). Species interactions (including through food webs considerations) is also a key component of the ecosystem approach to fisheries (FAO, 2003).

Another important principle of the Action Plan concerns the planning scales and inclusivity – it states that restoration activities should be planned at **various scales** and implemented by making use of best available science and traditional knowledge, and with prior informed consent and

[2] The ecosystem approach principles are the following: 1. The objectives of management of land, water and living resources are a matter of societal choice; 2. Management should be decentralized to the lowest appropriate level; 3. Ecosystem managers should consider the effects (actual and potential) of their activities on adjacent and other ecosystems; 4. Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem-management program should (a) reduce those market distortions that adversely affect biological diversity; (b) align incentives to promote biodiversity conservation and sustainable use; (c) internalize costs and benefits in the given ecosystem to the extent feasible; 5. Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach; 6. Ecosystems must be managed within the limits of their functioning; 7. The ecosystem approach should be undertaken at the appropriate spatial and temporal scales; 8. Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term; 9. Management must recognize that change is inevitable; 10. The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity; 11. The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices; 12. The ecosystem approach should involve all relevant sectors of society and scientific disciplines (CBD decision VII/11 (2004), Annex I, Table 1).

full and effective participation of indigenous peoples and local communities, engagement of women and other relevant stakeholders (CBD decision XIII/5 (2016), Annex, para. 10).

The Action Plan recommends undertaking (or making use of existing) broad-scale ecosystem **assessments**, including mapping (CBD decision XIII/5 (2016), Annex, para. 13). Assessments should include the following components:

i. assessment of the extent, type, degree and location of degraded ecosystems;
ii. identification and prioritisation of geographical areas where restoration could contribute the most to priority areas for biodiversity conservation and ecosystem services, and enhancing the integrity of protected areas;
iii. involvement of indigenous peoples and local communities and relevant stakeholders;
iv. assessment of the potential costs (including of inaction) and multiple biodiversity and ecosystem services and socio-economic benefits of ecosystem restoration at relevant scales;
v. assessment of relevant institutional, policy, and legal frameworks;
vi. identification of options to reduce or eliminate drivers of biodiversity loss and ecosystem degradation at various scales (CBD decision XIII/5 (2016), Annex, paras .13(1)-(6)).

Other detailed recommendations contained in the Action Plan include specific actions concerning the improvement of the institutional enabling environment for ecosystem restoration, planning and implementation of activities, and monitoring, evaluation, feedback and dissemination of results (sections B-D of the Annex to CBD decision XIII/5 (2016)). Furthermore, Appendix I of this Action Plan contains guidance for integrating biodiversity considerations into ecosystem restoration. Some of the recommendations contained in the guidance include:

- Addressing the **drivers of biodiversity loss**, fragmentation, pollution, and over-exploitation.
- Making use of research on **species functions in ecosystems** and linkages between ecosystem functioning and services.
- Prioritising **restoration of habitats important for the reproduction and recovery of species**. Habitat is defined under the Convention as "the place or type of site where an organism or population naturally occurs" (CBD, Art. 2).
- Considering that **natural regeneration** may allow a degraded area to recover on its own after the removal or reduction of drivers of fragmentation, degradation and loss.
- Site-based actions be integrated within **seascape** practices, including by promoting restoration in proximity to **species refugia**, promoting **connectivity**, and creating **buffer zones** (CBD decision XIII/5 (2016), Appendix I).

Appendix II of the CBD Ecosystem Restoration Action Plan contains an indicative timeline for short-term activities (based on those included in the Plan as discussed above; i.e., assessments, institutional enabling environment, planning and implementation, monitoring, evaluation, feedback and dissemination of results) ranging from one to three years to three to six years for all proposed actions within each grouping (CBD decision XIII/5 (2016), Appendix II).

CBD Parties have reported taking some of these actions as part of their efforts to achieve Aichi Biodiversity Target 15 (CBD Secretariat, 2020). GBO-5 noted a surge in projects to restore coastal ecosystems (e.g., mangroves, seagrass meadows, kelp forests, coral and oyster reefs) in the past two decades, although not significantly enough qualitatively and quantitatively to have achieved the target (CBD Secretariat, 2020).

4.1.2 Kunming-Montreal Global Biodiversity Framework

In 2022, the Kunming-Montreal Global Biodiversity Framework (GBF) was adopted by CBD COP 15, replacing the 2011-2020 Strategic Plan for Biodiversity and its Aichi Biodiversity Targets

(CBD decision 15/4 (2022)). The theory of change behind the GBF recognises the urgent need for policy action to achieve sustainable development to reduce and/or reverse the drivers of biodiversity loss "to allow **recovery of all ecosystems** and to achieve the Convention's Vision of living in harmony with nature **by 2050**" (CBD decision 15/4 (2022), Annex, para. 9).

As discussed above, the **2050 vision** of the GBF continues to be the same as of the 2011-2020 Strategic Plan, namely, "**by 2050**, biodiversity is valued, conserved, **restored** and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people" (CBD decision 15/4 (2022), Annex, para. 10, emphasis added). The GBF's 2030 **mission** towards the achievement of the 2050 vision is the following:

"To take urgent action to **halt and reverse** biodiversity loss to put nature on a **path to recovery** for the benefit of people and planet **by conserving and sustainably using biodiversity** and by ensuring the fair and equitable sharing of benefits from the use of genetic resources, while providing the necessary means of implementation" (CBD decision 15/4 (2022), Annex, para. 11, emphasis added).

Four 2050 **goals** have also been set under the Framework. Of direct relevance to ecosystem restoration are Goals A and B. **Goal A** states the following:

"The integrity, connectivity and resilience of all ecosystems are maintained, enhanced, or **restored**, substantially increasing the area of natural ecosystems by 2050;

Human induced extinction of known threatened species is halted, and, by 2050, the extinction rate and risk of all species are reduced tenfold and the abundance of native wild species is increased to healthy and resilient levels;

The genetic diversity within populations of wild and domesticated species, is maintained, safeguarding their adaptive potential." (CBD decision 15/4 (2022), Annex, para. 12, Goal A).

Goal B states that "**biodiversity** is sustainably used and managed and nature's contribution to people, **including ecosystem functions and services**, are valued, maintained and enhanced, **with those currently in decline being restored**, supporting the achievement of sustainable development for the benefit of present and future generations by 2050" (CBD decision 15/4 (2022), Annex, para 12, Goal B, emphasis added).

Twenty-three targets were adopted under the Framework – all of which to be achieved by 2030. Of particular relevance to restoration is **Target 2** that commits Parties to: "Ensure that **by 2030 at least 30 per cent of areas of degraded** terrestrial, inland water, and **marine and coastal ecosystems are under effective restoration**, in order **to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity**" (CBD decision 15/4 (2022), Annex, para. 13, Target 2).

GBF Target 2 is therefore about restoring **ecosystems**, not only individual species. Ecosystem is defined by the CBD as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as functional unit" (CBD, Art. 2). The CBD Secretariat's Guidance Notes on this target defines the terms contained in Target 2 (see Table 4.1 below). The Guidance Notes highlight that under Target 2, it is not required that restoration has taken place by 2030, but that degraded marine and coastal areas be **under effective restoration** by then. This aligns with the GBF Goal mentioned above of having the integrity, connectivity and resilience of all ecosystems maintained, enhanced, or **restored by 2050**. The Guidance Notes also highlight that **the objective of Target 2** is not restoration per se, but through restoration the aim is **to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity**.

Table 4.1. Definition of terms contained in GBF Target 2. Source: CBD Secretariat's GBF Guidance Notes. Online: https://www.cbd.int/gbf/targets/2

Term	Definition
Restoration	The process of actively managing the recovery of an ecosystem that has been degraded, damaged or destroyed. Restoration activities can be undertaken for a variety of reasons and across a continuum of actions. For example, ecological restoration includes efforts to increase the area of a natural ecosystem and its integrity through recovering an ecosystem that has been degraded or destroyed, this includes conversion of non-natural transformed ecosystems back to a natural ecosystems state. On the other hand ecosystem rehabilitation includes efforts to increase ecosystem functions and services of transformed ecosystems. Given, the continuum of restoration activities, efforts to reach this target should be specific and identify the type of restoration being undertaken, the overall objectives being sought and the type of area or ecosystem being restored.
Effective	In order for restoration activities to be effective, they need to be appropriately resourced and monitored over time. Further, the potential for restoration should not be regarded as a justification for the further degradation of ecosystems. The target does not require areas to be restored, given that restoration is a long-term process, but that effective restoration activities have been initiated.
Degraded Ecosystems	A persistent (long-term) reduction in the capacity to provide ecosystem services. Degraded land includes natural ecosystems which have included a loss of ecosystem functions and services and transformed ecosystems (such as agricultural areas). An assessment of degraded areas within a country is a necessary first step for monitoring the total percent of degraded ecosystems which are under restoration.
Terrestrial, inland water, marine and coastal ecosystems	The Target specifies the need to restore all types of ecosystems whether terrestrial, inland water or marine and coastal.
Enhance biodiversity and ecosystem functions and services	While restoration activities can be undertaken for various reasons, this target specifies that such activities should be undertaken for the purposes of enhancing biodiversity and ecosystem functions and services, ecological integrity and connectivity. These different objectives should be considered in the design and implementation of actions to reach this target.
Connectivity and integrity	An area with high ecological integrity is one which has a composition, structure, function and ecological process close to that of a natural ecosystem. Connectivity ensures the maintenance of natural species habitats. Taking into account both objectives is an important consideration in the design of restoration activities.

The GBF targets are complemented by indicators to monitor progress toward their achievement (CBD decision 15/5 (2022)). The indicators for Target 2, incorporated under the GBF Monitoring Framework (CBD/COP/16/L.26/Rev.1 (2025), include:

- Area under restoration by ecosystem functional group (Global Ecosystem Typology levels 2 and 3 or equivalent), by indigenous and traditional territories, by protected areas or OECMs, by type of restoration activity;
- Proportion of land that is degraded over total land area;
- Global Ecosystem Restoration Index;
- Proportion of key biodiversity areas in favourable condition.

Other GBF targets are also relevant to marine ecosystem restoration but not as directly as Target 2. For instance, Target 1 on biodiversity-inclusive marine spatial planning, Target 3 on marine protected areas (MPAs) and OECMs, Target 4 on recovery and conservation of species, Target 5 with respect to sustainable fisheries, Target 6 on invasive alien species, Target 7 on pollution, and Target 8 on climate change and ocean acidification are also relevant for restoration efforts in complementary ways. For instance, if read together, Targets 2 and 8 align well with the focus of (the previous) Aichi Biodiversity Target 15 on restoration of biodiversity degraded areas that contribute to climate change mitigation and adaptation (in line with the United Nations Framework Convention on Climate Change (UNFCCC) and Paris Agreement). Target 8 of the GBF commits Parties to: "Minimize the impact of climate change and ocean acidification on **biodiversity** and **increase its resilience** through mitigation, adaptation, and disaster risk reduction actions, including through **nature-based solutions and/or ecosystem-based approaches**, while minimizing negative and fostering positive impacts of climate action on biodiversity" (CBD decision 15/4 (2022), Annex, Target 8, emphasis added). Also very relevant is **GBF Target 11** which commits Parties to: "**Restore, maintain and enhance nature's contributions to people**, including ecosystem functions and services, such as the regulation of air, water and climate, soil health, pollination and reduction of disease risk, as well as protection from natural hazards and disasters, through nature-based solutions and/or ecosystem-based approaches for the benefit of all people and nature" (CBD decision 15/4 (2022), Annex, Target 11, emphasis added[3]).

Understanding the synergies across the different GBF targets can help guide their implementation (e.g. through the exploration of the role of nature-based solutions[4] and ecosystem approaches in restoration, the role of MPAs and OECMs in restoration and in ensuring ecological connectivity, etc). Nevertheless, it is also important to recognise that the focus of GBF Target 2 on restoration is broader than the previous focus of the Aichi Target 15. Target 2's emphasis on enhancing ecosystem functions and services, ecological integrity and connectivity in the context of ecosystem restoration provide an important indication of elements to be pursued in implementing the target.

4.1.3 Other Relevant CBD Decisions and Documents

In response to the adoption of the GBF, CBD COP 16 reviewed the **CBD marine and coastal biodiversity programme of work** (PoW) and concluded that together with relevant COP decisions, the PoW "still correspond to global priorities and contain guidance that provide essential support for the implementation of the Framework" (CBD decision 16/17 (2024), para. 4). At the same time, COP also noted that for certain elements of the GBF targets there is limited guidance or available tools for their implementation (CBD decision 16/17 (2024), para. 5). Marine restoration was identified as one of these elements in need of additional focus under the CBD to support implementation of the GBF Target 2, as follows: "To enhance understanding of the scope and extent of degraded marine and coastal areas and the complexities of **marine and coastal ecological restoration**, and to enhance the use of active and passive restoration, including ecological

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[3] Nature's contributions to people is defined by the IPBES as "all the contributions, both positive and negative, of living nature (i.e., diversity of organisms, ecosystems, and their associated ecological and evolutionary processes) to the quality of life for people. Beneficial contributions from nature include such things as food provision, water purification, flood control, and artistic inspiration, whereas detrimental contributions include disease transmission and predation that damages people or their assets. Many nature's contributions to people may be perceived as benefits or detriments depending on the cultural, temporal or spatial context." IPBES Glossary. Online: https://www.ipbes.net/glossary/natures-contributions-people [Accessed 29 January 2025].

[4] The definition of nature-based solutions by the United Nations Environment Assembly (UNEA) is the following: "actions to protect, conserve, **restore**, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits" UNEA resolution 5/5 (2022), para. 1.

restoration, in marine and coastal areas, building on experiences **across various ecosystems and sectors and on different scales**" (CBD decision 16/17 (2024), Annex, para. 1(a), emphasis added).

Although not comprehensively addressed previously, some other CBD decisions apply to marine and coastal restoration. Some of these include the following:

(i) **Relevant elements of the Marine and Coastal Biodiversity Programme of Work**: Under Operational objective 1.2 to undertake direct action to protect the marine environment from negative impacts, the following recommended activity is relevant: "to promote adequate protection of **areas important for reproduction such as spawning and nursery areas and restoration of such areas and other important habitats for marine living resources**" (CBD decision VII/5 (2004), operational objective 1.2 (a), emphasis added). Also, the following recommended activity under Operational Objective 1.3 of the PoW is relevant: "To promote the identification of key habitats for marine living resources on a regional basis, with a view to further develop policies for action to prevent physical alteration and destruction of these habitats, and pursue **restoration of degraded habitats, including, inter alia, coral reef systems**" (CBD decision VII/5 (2004), Operational objective 1.3 (c), emphasis added).

Furthermore, also important is the operational objective 2.3 of the PoW, which recommends the gathering and assimilation of information on, the building of capacity to mitigate the effects of, and the promotion of policy development, implementation strategies and actions to address:

(i) the biological and socio-economic consequences of physical degradation and destruction of key marine and coastal habitats including mangrove ecosystems, tropical and cold-water coral-reef ecosystems, seamount ecosystems and seagrass ecosystems including identification and promotion of management practices, methodologies and policies to reduce and mitigate impacts upon marine and coastal biological diversity and to restore mangrove forests and rehabilitate damaged coral reef.

(ii) **CBD decision X/29 (2010) on marine and coastal biodiversity** urged Parties to stop the degradation and loss of **ecologically important ecosystems and habitats, including estuaries, coastal sand dunes, mangroves, saltmarshes, seagrass beds, and biogenic reefs to support their recovery through the management of impacts and restoration** where appropriate (para. 72).

(iii) The **Key Messages from the Scientific Compilation and Synthesis on Biodiversity and Ocean Acidification in Cold-Water Areas** did not directly address ecological restoration. However, it identified management areas that require improvement that could help address some of the elements of Targets 2 and 3 (e.g. connectivity), and 8 (e.g., climate change and ocean acidification) of the GBF. For instance, it states that: "Scientific studies suggest that **priority areas for protection** should include areas that are **resilient to the impacts of climate change** and thus act as refuges for important biodiversity. In cold-water coral reefs, this may include **important reefs strongholds** (reef areas likely to be less impacted by acidification because they are located at depths above the aragonite saturation horizon), **or areas important for maintaining reef connectivity and gene flow**, which may be crucial for coral species to adapt to the changing conditions" (CBD decision XIII/11 (2016), Annex I, para. 25).

In this context, the **Voluntary Specific Workplan on Biodiversity in Cold-water Areas within the Jurisdictional Scope of the Convention** recommends the identification and protection of refugia sites and the adoption of conservation measures to enhance the adaptive capacity of cold-water ecosystems (CBD decision XIII/11 (2016), Annex II, para. 4 (c)). The workplan also recommended the **identification and prioritisation in conservation, protection and management approaches cold-water areas such as, inter alia, habitats that are important for maintaining connectivity, gene pool size and diversity and gene flow, and representative benthic habitats across the range of ecosystems, including those adjacent to degraded areas** (CBD decision XIII/11 (2016), Annex II, para. 5.3).

(iv) **CBD decisions on biodiversity and climate change** are also relevant to ecological restoration. For instance, decision 14/5 (2018) encourages Parties to further strengthen their efforts to "promote ecosystem restoration and sustainable management post-restoration" (CBD decision 14/5 (2018), para. 4 (c)). The same decision adopted the **Voluntary Guidelines for the Design and Effective Implementation of Ecosystem-based Approaches to Climate Change Adaptation and Disaster Risk Reduction**. These guidelines define 'ecosystem-based disaster risk reduction' (Eco-DRR) as "the holistic, sustainable management, conservation and **restoration** of ecosystems to reduce disaster risk, with the aim of achieving sustainable and resilient development" (CBD decision 14/5 (2018), Annex, para. 2, emphasis added). Some of the marine and coastal ecosystem-based adaptation and Eco-DRR interventions contained in the guidelines include mangrove restoration and coastal protection, sustainable fishing and mangrove rehabilitation, and coral reef restoration (CBD decision 14/5 (2018), Annex, para. 5). The guidelines are complementary to other guidance adopted under the CBD, including the Ecosystem Restoration Short-term Action Plan discussed above (CBD decision 14/5 (2018), Annex, para. 8). These guidelines also note the importance of applying a **precautionary approach in planning and implementing ecosystem-based adaptation and Eco-DRR**, including by applying **environmental impact assessments, preventing transferring risks and impacts to other areas, preventing harm to biodiversity, ecosystems and ecosystem functions and services, promoting full and effective participation**, among others (CBD decision 14/5 (2018), Annex, para. 8).

The most recent biodiversity and climate change decision from 2024 emphasised that: "biodiversity and ecosystem integrity play an important role in combating climate change and its impacts and that **conserving and restoring biodiversity and ecosystems, inclusive of animal populations, are effective options for mitigation, adaptation and disaster risk reduction and constitute actions towards minimizing the impacts of climate change**, in particular when the knowledge, governance and stewardship practices of indigenous peoples and local communities are integrated" (CBD decision 16/22 (2024), 10th preambular paragraph, emphasis added).

Parties were urged to, when taking actions to achieve GBF Targets 8 and 11, and other related targets, identify and maximise synergies between biodiversity and climate actions, "including by **prioritizing the protection, restoration and management of ecosystems and species important for the full carbon cycle and contributing to climate change adaptation**" (CBD decision 16/22 (2024), para. 3 (b), emphasis added). Conversely, Parties also committed to, inter alia, **avoid or minimise the negative impacts of climate actions on biodiversity, ecosystem integrity, functions and services** (CBD decision 16/22 (2024), para. 3 (c)). In the pursuit of policy coherence, the CBD Secretariat was requested by COP 16 "to promote synergies and closer cooperation with biodiversity-relevant multilateral environmental agreements, organisations and processes and integrated approaches to addressing biodiversity loss, climate change and land and ocean degradation" (CBD decision 16/22 (2024), para. 14). In the same COP decision, the Secretariat was also requested to develop guidelines and tools for carrying out conservation and restoration in a changing climate (CBD decision 16/22 (2024), para. 18).

(v) **Ecologically or Biologically Significant Marine Areas (EBSAs) decisions (as tools to identify areas of interest)**: EBSAs are areas important for marine and coastal biodiversity that have been described in accordance with scientific and technical criteria contained in CBD decision IX/20 (2008), Annex I[5]. These descriptions do not have any management consequences, but they can inform conservation and sustainable management by States and competent organisations

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[5] The EBSA criteria are the following: uniqueness or rarity; special importance for life-history of species; importance for threatened, endangered or declining species and/or habitats; vulnerability, fragility, sensitivity, or slow recovery; biological productivity; biological diversity; naturalness.

(CBD decision X/29 (2020); CBD decision 16/16 (2024)). As such EBSA descriptions can inform restoration measures including by providing relevant baseline information on the condition of specific habitats at the time of their original description. To be described as an EBSA, an area does not have to meet all seven criteria, and in this sense, these descriptions can also point to areas that are important for biological productivity, areas that are important for threatened or declining species and areas important for their life-history stages (see EBSA criteria contained in CBD decision IX/20 (2008), Annex I), which are important considerations in restoration activities.

The process for describing EBSAs under the CBD is contained in decision X/29 (2010), and more recently updated through decision 16/16 (2024). Decision 16/16 (2024) recognises that the description of EBSAs "is an important scientific and technical process that can make a crucial contribution to the implementation of the Kunming-Montreal Global Biodiversity Framework and the Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction" (BBNJ Agreement) (CBD decision 16/16 (2024), 4th preambular paragraph).

Over the past decade, more than 300 EBSAs have been described across the world's oceans and the biological and ecological information contained therein could inform restoration efforts in cases of degradation of the site, or biodiversity loss. For instance, the first criterion (**importance for threatened, endangered or declining species and/or habitats**) is defined as an "area containing habitat for the survival and recovery of endangered, threatened, declining species or area with significant assemblages of such species" (CBD decision IX/20 (2008), Annex I). The rationale for the inclusion of this criterion was to ensure the restoration and recovery of such species and habitats (CBD decision IX/20 (2008), Annex I). Examples of such areas include breeding grounds, spawning and nursery areas, habitat for juvenile species and other areas important for life-history stages of species, habitat and routes for migratory species (CBD decision IX/20 (2008), Annex I).

Areas containing a relatively high proportion of sensitive habitats, biotopes or species functionally fragile or with slow recovery fit within the second EBSA criterion (vulnerability, fragility, sensitivity, or slow recovery) (CBD decision IX/20 (2008), Annex I). VMEs are examples of such areas. The third criterion (**biological productivity**) is defined as areas containing species, populations or communities with comparatively higher natural biological productivity (CBD decision IX/20 (2008), Annex I). The rationale for this criterion is based on their role to fuel ecosystems and enhancing the growth rates of organisms and their reproductive capacity (CBD decision IX/20 (2008), Annex I). Examples of such areas include frontal zones, upwelling areas, hydrothermal vents, seamounts, and polynyas (CBD decision IX/20 (2008), Annex I).

The **biological diversity** criterion is defined in the context of EBSAs as areas containing comparatively higher diversity of ecosystems, habitats, communities, or species or areas with higher genetic diversity (CBD decision IX/20 (2008), Annex I). These areas are important for evolution and resilience of marine species and ecosystems (CBD decision IX/20 (2008), Annex I).

(vi) **The priority actions** to achieve Aichi Biodiversity Target 10 **for coral reefs and closely associated ecosystems** makes a series of recommendations, including **to prioritise the recovery and sustainable management of reef species with key ecological functions, in particular herbivores reef fish populations** (CBD decision XII/23 (2014), Annex, para. 8.1 (f)).

It is important to note that the 2019 CBD Marine and Coastal Biodiversity thematic workshop, which contributed to the development of the GBF, emphasised that marine ecosystems are able to rebuild if proper measures are in place (CBD/POST2020/WS/2019/10/2, 2019). For instance, with regards to coral reefs, it has been noted that the "removal of the direct local pressures, which currently threaten 60% of reefs globally, would give the ecosystems the time and space to be able to respond and adapt to the projections for changing climatic conditions" (CBD/POST2020/WS/2019/10/2, 2019, p. 19).

4.2 International Fisheries Law and Policy

Restoration can also be an important intervention in fisheries management, including through habitat or ecosystem restoration (in line with GBF Target 2), or by restoring or rebuilding stocks to health levels (in line with GBF Targets 4, 5 and 10). UNCLOS' (1982) obligation to protect and preserve the marine environment (as per Arts 192 and 194 (5) as discussed above) are therefore relevant to fish habitats. Furthermore, UNCLOS (1982) Parts V (on the exclusive economic zone - EEZ) and VII (on the high seas) contain specific provisions on sustainable fisheries that are worth noting. For instance, Coastal States must ensure "through proper conservation and management measures [taking into account the best scientific evidence available] that the maintenance of the living resources in the exclusive economic zone is not endangered by over-exploitation" (UNCLOS, 1982; Art. 61 (2)). Moreover, "such measures shall be designed to maintain or **restore** populations of harvested species at levels which can produce the **maximum sustainable yield [MSY],** as qualified by relevant environmental and economic factors, including the economic needs of coastal fishing communities and the special requirements of developing States, and taking into account fishing patterns, the interdependence of stocks and any generally recommended international minimum standards, whether subregional, regional or global" (UNCLOS, 1982; Art. 61 (3), emphasis added).

States have similar obligations when fishing on the high seas (see UNCLOS, 1982; Art. 119). States shall "take measures which are designed on the best scientific evidence available to the States concerned, to maintain or **restore** populations of harvested species" to MSY levels "… and taking into account fishing patterns, the interdependence of stocks and any generally recommended international minimum standards, whether subregional, regional or global" (UNCLOS, 1982; Art. 119 (1) (a), emphasis added).

In both cases (in EEZs and in the high seas), generally recommended international minimum standards shall be taken into account in the design of fisheries conservation and management measures (UNCLOS, 1982; Arts. 61(3) and 119(1)(a)). As such, standards may be contained in policy instruments (and not only in legally binding instruments), such as UNGA resolutions, COP decisions of relevant treaties (e.g. CBD), FAO guidelines, among others (see Boyle and Redgwell, 2021).

Sustainable Development Goal (SDG) 14.4 on sustainable fisheries is an example of such standards. The SDGs were adopted by UNGA resolution 70/1 (2015). The intent of SDG 14.4 is "to **restore** fish stocks in the shortest time feasible, **at least to levels** that can produce maximum sustainable yield as determined by their biological characteristics" by 2020 (UNGA resolution 70/1 (2015), SDG 14.4). This target has not been achieved and implementation continues to be monitored (United Nations, 2024), as part of the **2015-2030 timeframe** of the UN Agenda for Sustainable Development. In the latest SDG progress assessment, it was noted that there has been a regression in the achievement of Target 14.4. With respect to the SDG 14.4 threshold of at least MSY levels, this goes beyond UNCLOS' aim to restore stocks to MSY levels as a target reference point rather than as a limit. This SDG 14.4 approach partly reflects the concept of precautionary reference points included in the UN Fish Stocks Agreement (UNFSA).

In this regard, UNFSA contains specific obligations on how to set precautionary reference points for maintaining or **restoring populations of harvested stocks, as well as associated or dependent species**, (UNFSA, Art. 6 and Annex II). Aligned with SDG 14.4, Annex II of UNFSA (on guidelines for the application of precautionary reference points in conservation and management of straddling fish stocks and highly migratory fish stocks) states that, inter alia, "the fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points" (UNFSA, Annex II, para. 7). Aligned with this, the UNGA resolution 79/145 (2024) called upon all States, directly or through RFMOs, "to apply stock-specific target and limit precautionary reference points, which for target reference points, are intended to meet management objectives, as described in Annex II to the Agreement (…) to ensure that populations of harvested stocks, and where necessary, associated or dependent species are maintained at or restored to sustainable levels, and to use these reference points for triggering conservation and management action" (UNGA resolution 79/145 (2024), para. 24). These provisions align with GBF Target 4 on species, which reads: "Ensure urgent management actions to halt human induced extinction of known threatened species and for the **recovery and conservation of species**, in particular threatened species, to significantly reduce extinction risk, **as well as maintain and restore the genetic diversity within and between populations of native, wild and domesticated species to maintain their adaptive potential**, including through in situ and ex situ conservation and sustainable management practices, and effectively manage human-wildlife interactions to minimize human-wildlife conflict for coexistence." (CBD decision 15/4 (2022), Annex, Target 4).

UNFSA's obligations on the precautionary approach to fisheries provides guidance on how to recover fish stocks from threatened levels (straddling or highly migratory, as well as associated or dependent species). These obligations are not restricted to a proportion of the species or of the stocks. They encompass all straddling and highly migratory fish stocks and those belonging to the same ecosystem (UNFSA, Art 6). However, it is important to note that UNFSA does not have the same amount of Parties as the CBD, and therefore, UNFSA obligations on fish stocks rebuilding would not necessarily apply to all CBD Parties. Exceptions apply in cases CBD Parties are members of RFMOs that have included the precautionary approach to fisheries into their Conventions or regulatory measures.

Another relevant global instrument is the World Trade Organization Agreement on Fisheries Subsidies, which was adopted at the 12th Ministerial Conference (MC12). Article 4 relates to subsidies regarding overfished stocks and states that "no Member shall grant or maintain subsidies for fishing or fishing related activities regarding an overfished stock", which can be seen as a policy instrument aiming at restoring fish populations.

Rebuilding or restoring fish stocks – although complementary to GBF Target 2 on ecosystem restoration - seem to fit better within GBF Targets on species and fisheries more specifically, such as Targets 4, 5 and 10. That is because as seen above, Target 2 focuses on ecosystem/area restoration more broadly. In this regard, UNFSA's provisions related to the **ecosystem approach to fisheries** (see also FAO, 2003) seem relevant for achieving these global targets as a whole. For instance, the following obligations are important, inter alia:

i. to ensure that conservation and management measures are based on best scientific evidence and takes into account the interdependence of stocks (i.e., food webs) (UNFSA, Art. 5(b))
ii. to adopt conservation and management measures for species belonging to the same ecosystem or associated with or dependent upon the target stocks (UNFSA, Art 5 (e));
iii. to minimise pollution, bycatch and impacts on associated or dependent species (UNFSA, Art. 5(f));
iv. to assess the impacts of fishing, other human activities and environmental factors on target stocks and species belonging to the same ecosystem or associated with or dependent upon the target stocks (UNFSA, Art. 5(d)); and
v. to protect marine biodiversity (UNFSA, Art. 5(g)).

These provisions are not only are essential to the achievement of GBF Target 4 on recovery and conservation of species, Targets 5 and 10 on fisheries, but also to GBF Target 2 on ecosystem restoration (among other targets), as further discussed below.

The UNGA resolution on sustainable fisheries has also stated that the UN Decade of Ocean Science for Sustainable Development and the UN Decade on Ecosystem Restoration provide opportunities to "prevent, halt and **reverse the degradation of ecosystems** worldwide" (UNGA resolution 79/145 (2024), 10th preambular paragraph). Furthermore, the resolution has also encouraged Parties to the CBD to fully and effectively implement the GBF and its targets relevant to fisheries (UNGA resolution 79/145 (2024), para 21). In this regard, Targets 5 and 10 of the GBF are the most directly relevant ones[6], although all the other targets discussed in this section (among others) also have implications to fisheries management. The UNGA resolution has also urged further efforts by RFMOs and arrangements **as a matter of priority** to implement modern approaches including the **precautionary approach and ecosystem approach to fisheries management "including the conservation and management of ecologically related and dependent species and protection of their habitats**" (UNGA resolution 79/145 (2024), para 185).

With regards to **deep-sea ecosystems** several UNGA resolutions on sustainable fisheries have called for the prevention of significant adverse impacts (SAI) on vulnerable marine ecosystems (VMEs) (e.g. UNGA resolutions 61/105 (2006); 64/72 (2009); 66/68 (2011); 71/123 (2016); 77/118 (2022); see also ICES, 2024). The FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas describe the characteristics of vulnerable marine ecosystems (VMEs) and define **significant adverse impacts as those that compromise ecosystem integrity, namely ecosystem structure or function** in a way that: "(i) impairs the ability of affected populations to replace themselves; (ii) degrades the long-term natural productivity of habitats; or (iii) causes, on more than a temporary basis, significant loss of species richness, habitat or community types" (FAO, 2009, para. 17).

While the focus of these policy instruments are on the prevention of SAI, **the ability of an ecosystem to recover from harm and the rate of recovery** constitute one of the six factors that should be considered when assessing SAI. The FAO Guidelines note that "[i]f the interval between the expected disturbance of a habitat is shorter than the recovery time, the impact should be considered more than temporary" (FAO, 2009, para. 20). The FAO Guidelines expressly state that "[t]hese Guidelines are to be interpreted and applied in conformity with the relevant rules of international law, as reflected in the United Nations Convention on the Law of the Sea of 10 December 1982" (FAO, 2009, para. 7). Conversely, these Guidelines also support the implementation of UNCLOS' provisions on the conservation of living marine resources by providing generally agreed standards for deep-sea fisheries, and providing guidance on how to protect and preserve the marine environment from SAI (see the introductory note in this Section 4 above).

If the interpretation of ITLOS is correct that the obligation to 'preserve the marine environment' under UNCLOS may include the obligation to restore ecosystems (ITLOS, 2024), it is possible to assume that the FAO guidance can also be used not only to prevent SAI, but also to restore areas

[6] Target 5 reads: "Ensure that the use, harvesting and trade of wild species is sustainable, safe and legal, preventing overexploitation, minimizing impacts on non-target species and ecosystems, and reducing the risk of pathogen spillover, applying the ecosystem approach, while respecting and protecting customary sustainable use by indigenous peoples and local communities". And Target 10 reads: "Ensure that areas under agriculture, aquaculture, fisheries and forestry are managed sustainably, in particular through the sustainable use of biodiversity, including through a substantial increase of the application of biodiversity friendly practices, such as sustainable intensification, agroecological and other innovative approaches, contributing to the resilience and long-term efficiency and productivity of these production systems, and to food security, conserving and restoring biodiversity and maintaining nature's contributions to people, including ecosystem functions and services." (CBD decision 15/4 (2022), Annex, Targets 5 and 10).

where VMEs are likely to occur or have occurred but have been degraded. Such interpretation is also possible in light of the GBF Target 2 language on ensuring that (at least 30% of) degraded marine ecosystems are under effective restoration (which can be active or passive) to enhance biodiversity, ecosystem functions and services, ecological integrity and connectivity (CBD decision 15/4 (2022), Annex, Target 2).

4.3 Marine Biodiversity of Areas Beyond National Jurisdiction under the BBNJ Agreement

The BBNJ Agreement (United Nations, 2023) contains three references to restoration. Among its general principles and approaches that shall guide Parties to achieve the objectives of the Agreement concerning the conservation and sustainable use of marine biodiversity of areas beyond national jurisdiction for **the present and in the long term**, the Agreement includes reference to ecosystem integrity restoration, as follows: "an approach that builds **ecosystem resilience**, including to adverse effects of climate change and ocean acidification, and also **maintains and restores ecosystem integrity**, including the carbon cycling services that underpin the role of the ocean in climate" (United Nations, 2023; BBNJ Agreement, Art. 7(h)).

The Agreement does not define "ecosystem integrity", but the CBD defines "ecosystem" as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" (CBD, Art. 2). Nelson et al (2024) define ecosystem integrity as "the degree to which an ecosystem's physical condition, structure and function are intact (that is, have not been degraded)" (Nelson et al., 2024, p. 85). This aligns with the definition of ecosystem integrity also provided by paragraph 17 of the FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO, 2009), which also refers to ecosystem structure or function. This definition is given in the context of assessing and avoiding significant adverse impacts on vulnerable marine ecosystems (VMEs) (see Section 4.2 above).

One of the main vehicles for achieving ecosystem restoration under the BBNJ Agreement is through the establishment of area-based management tools (ABMTs), including marine protected areas (MPAs). Among the objectives of Part III of the Agreement on ABMTs, including MPAs, is the objective to "**protect, preserve, restore and maintain biological diversity and ecosystems**, including with a view **to enhancing their productivity and health**, and **strengthen resilience** to stressors, including those related to climate change, ocean acidification and marine pollution" (United Nations, 2023; BBNJ Agreement, Art. 17 (c)). As such, one of the indicative criterion for the identification of areas for the establishment of ABMTs, including MPAs is "biological diversity and productivity" (BBNJ Agreement, Annex I, para. (i)). Other relevant indicative criteria include importance for threatened, endangered or declining species or habitats, vulnerability, fragility, ecological connectivity, and importance for ecological processes (United Nations, 2023; BBNJ Agreement, Annex I).

Furthermore, the BBNJ COP may consider establishing additional funds as part of the Agreement's financial mechanism to finance rehabilitation and **ecological restoration of marine biodiversity of areas beyond national jurisdiction** (United Nations, 2023; BBNJ Agreement, Art. 52 (5)).

The Agreement is not yet into force, and therefore, it is still not clear how the restoration objectives or related activities will be operationalised. Deliberations by the Scientific and Technical Body (STB) and by the COP on this topic will help clarify the implementation of these clauses in due course.

4.4 Migratory Species of Wild Animals

The Convention on Migratory Species (CMS) contains specific provisions on restoration, namely, Parties shall endeavour to conserve and when feasible and appropriate, restore the habitats of Appendix I species "which are of importance of removing the species from danger of extinction and to prevent, remove, compensate for or minimize, as appropriate, obstacles that seriously impede the migration of the species" (Convention on Migratory Species, 1979; Art. III (4)).

The CMS COP has recently adopted the **Samarkand Strategic Plan for Migratory Species 2024-2032** (UNEP/CMS/Resolution 14.1 (2024), which commits Parties to specific restoration actions. The Strategic Plan sets out a vision, **six goals to be achieved by 2032**, and several targets to be achieved within different timescales depending on their required action or envisioned outcome.

The **vision statement** of this Strategic Plan is that "**By 2032, migratory species are thriving** and live in **fully restored** and **connected habitats**" (UNEP/CMS/Resolution 14.1 (2024), Annex, vision, emphasis added). Habitat is defined under the Convention as "any area in the range of a migratory species which contains suitable living conditions for that species" (Convention on Migratory Species, 1979; Art. I (1) (g)).

More specifically, **Goal 2** of the Strategic Plan states that "the **habitats** and ranges of migratory species are maintained and **restored, supporting their connectivity**" (UNEP/CMS/Resolution 14.1 (2024), Annex, Goal 2, emphasis added). To achieve this goal, Targets 2.1-2.3 are relevant since they constitute a continuum of activities.

Target 2.1 establishes that **by 2029, all important habitats for CMS listed species "are identified, assessed and monitored** to ensure their **functionality and ability to support migratory species throughout their life cycles**." The CBD EBSA process discussed in subsection A above can be particularly relevant for this target.

Target 2.2 establishes that **by 2032, all important habitats for CMS listed species** are "protected, effectively conserved, managed and **restored through ecologically representative, well-connected and equitably governed systems of protected areas and OECMs**."

And finally, Target 2.3 establishes that by **2032**, "the **loss, degradation and fragmentation of important habitats** for [CMS listed species] **is reduced**, and **habitats are restored** to ensure that such habitats support their viability".

A strong emphasis of the CMS, including with respect to habitat restoration is on ecological connectivity, which has been defined by CMS COP as the unimpeded movement of species and the flow of natural processes that sustain life on Earth (UNEP/CMS/Resolution 12.26 (Rev. COP 13), 2020, 1st preambular paragraph). In the context of MPAs (relevant to Target 2.2 of the CMS Strategic Plan and GBF Target 3), the CBD criteria for designing ecologically representative MPA networks[7] (CBD decision IX/20 (2008), Annex II) can be particularly relevant.

4.5 Wetlands

The Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention) applies to wetlands (natural or artificial, permanent or temporary) with flowing or static water, "including areas of marine water the depth of which at low tide does not exceed six meters" (Ramsar Convention, 1971; Art. 1(1)). Parties to the Convention shall promote the conservation of wetlands and waterfowl by establishing nature reserves in these areas whether

[7] The network criteria include the following properties and components: EBSAs; representativity; connectivity; replicated ecological features; adequate and viable sites. For definition and application guidance of each one of these components see CBD decision IX/20 (2008), Annex II.

or not these are included in the Convention's List of Wetlands of International Importance (the List) (Ramsar Convention, 1971; Arts 2(1) and 4(1)). However, wetlands have declined by 35% since 1970 (Ramsar resolution XIV.16 (2022), para. 2), and between 64% and 71% in the 20th century (Convention on Wetlands, 2018). In 2002, the Ramsar Convention COP adopted Principles and Guidelines for wetland restoration (Ramsar resolution VIII.16 (2002)). These Principles and Guidelines **use the term 'restoration'** in a broad sense, including "projects that promote a return to original conditions and projects that improve wetland functions without necessarily promoting a return to pre-disturbance conditions" (Ramsar resolution VIII.16 (2002), para. 3).

More recently, Ramsar Convention COP has encouraged Parties to: "integrate wetland conservation, **restoration**, sustainable management and wise-use policies and actions into national sustainable development strategies, and to evaluate the role of wetland conservation and restoration in national and global sustainable development strategies in line with the 2030 Agenda for Sustainable Development, National Biodiversity Strategies and Action Plans (NBSAPs) under the [CBD] as well as nationally determined contributions and adaption plans under the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement (…)" (Ramsar Convention resolution XIV.16, 2022, para. 11).

In this context, Parties were also encouraged to set targets for wetland management, avoid, minimise or when needed compensate for the conversion of wetlands and ensure that environmental impact assessments (EIAs) are conducted with measures being identified to minimise impacts of projects on wetlands (Ramsar Convention resolution XIV.16, 2022), para. 17). CBD has useful guidance on biodiversity-inclusive EIAs that could be helpful in setting standards for such assessments (see CBD decision VIII/28 (2006); CBD decision XI/18 (2012)).

Furthermore, the Ramsar resolution also encouraged Parties to identify the status of national and local degraded wetlands and set restoration targets and take measures to improve their condition (Ramsar Convention resolution XIV.16, 2022, para. 18). In this respect Parties have also been encouraged to monitor their policies on a regular basis to restore wetlands (Ramsar resolution XIV.16 (2022), para. 19). Migratory connectivity of species has also been highlighted as an important element of restoration efforts (Ramsar Convention resolution XIV.16, 2022, para. 20).

More recently, the Ramsar Scientific and Technical Review Panel has produced a Technical Report on scaling up conservation and restoration to deliver the GBF. The report provides guidance to CBD Parties on how to include key actions to conserve and restore wetlands into their NBSAPs in relation to each GBF target (Convention on Wetlands, 2024). For instance, the report recommends that national targets should include plans to restore coastal wetland ecosystems in hectares (Convention on Wetlands, 2024). The report also recommends increasing the area of coastal and marine wetland ecosystems in protected areas and OECMs, with high biodiversity areas being prioritised (Convention on Wetlands, 2024). These high biodiversity areas include those areas described as EBSAs (as discussed above). The report also recommends prioritising wetland wildlife hotspots and ecological corridors, including flyways and swimways, in MPA and OECM network design (GBF Target 3), in restoration actions (GBF Target 2), and in halting species extinction (GBF Target 4) by enhancing and maintain connectivity.

Another recommendation was to improve data on wetlands (including by updating inventories) such as wetland extent, condition and biodiversity (Convention on Wetlands, 2024). The report notes the importance of wetlands, such as mangroves and mudflats, as important carbon sinks and therefore playing a role in nature-based solutions under GBF Target 8 (Convention on Wetlands, 2024; see also Convention on Wetlands (2018), which highlights the role of saltmarshes, mangroves and seagrasses in climate change mitigation). The also highlights the knowledge and expertise of Indigenous Peoples and local communities and their role in wetlands' conservation (Convention on Wetlands, 2024).

4.6 Regional Seas Organizations

Several **Regional Sea Organizations (RSOs)** have incorporated **restoration plans or strategies** as part of their efforts to protect and rehabilitate marine and coastal ecosystems. As further discussed in Section 5 below, these organizations play a key role in implementing international cooperation at the regional level, and therefore, they are well placed to promote or implement restoration of marine habitats and ecosystems and in doing so, to take into account ecological connectivity considerations (see Section 5). While not all of them explicitly focus on **restoration**, many have developed strategies that include elements of **ecosystem recovery, habitat restoration, and conservation**.

Examples of Regional Sea Conventions with Restoration Plans/Strategies:

1. **OSPAR Convention (North-East Atlantic)**
   - The **North-East Atlantic Environment Strategy 2030** includes commitments to restore marine ecosystems. Strategic objective 6: Restore degraded habitats in the North-East Atlantic when practicable to safeguard their ecosystem function and resilience to climate change and ocean acidification.
2. **HELCOM (Baltic Sea)**
   - The **Baltic Sea Action Plan (BSAP) (HELCOM ACTION, 2021)** has specific targets for **eutrophication reduction, biodiversity restoration, and habitat recovery**, inter alia Action B27 on developing a Regional Action Plan for habitat and biotope restoration.
3. **Barcelona Convention (Mediterranean)**
   - The **Post-2020 Strategic Action Programme for the Conservation of Biodiversity and Sustainable Management of Natural Resources in the Mediterranean Region** (Post-2020 SAPBIO, 2021) includes actions related to **ecosystem restoration**, specifically Action 12.

4.7 Ecosystem Restoration Implementation through Law: The EU Nature Restoration Law

The European Union (EU) Biodiversity strategy for 2030 (COM/2020/380) is a key pillar of the European Green Deal (COM/2019/640), aiming to halt biodiversity loss and restore degraded ecosystems across EU lands and waters. Launched in 2020, the strategy outlines a comprehensive plan to protect and restore biodiversity, with specific actions and commitments.

Key commitments for nature protection by 2030 include:

- Legally protecting at least 30% of EU land and sea areas, with the aim of expanding and completing the Nature 2000 Network;
- Strictly protecting at least one-third of the protected areas, focusing on highly biodiverse habitats;
- Ensuring effective management of all protected areas (COM/2020/380, p. 5).

Recognizing that protection alone is insufficient to reverse biodiversity loss, the EU Biodiversity strategy emphasizes the importance of active restoration efforts to rebuild ecosystems and meet climate goals. In addition, the Criteria and guidance for protected areas designations, developed by the European Commission (EC) in 2022, discusses that restored areas meeting the criteria for protected areas may contribute toward the EU's target for protected area coverage. Conversely, protected areas can play a significant role providing favorable conditions for successful restoration efforts (SWD (2022) 23 final, p. 10). In this regard, strictly protected areas may authorize active management, including nature restoration (SWD (2022) 23 final, p. 19).

This vision paved the way for the EU Nature Restoration Law, transforming the ambitions of the EU Biodiversity Strategy into binding legal obligations, compelling Member States to turn aspirations into actionable commitments for the restoration of EU marine and terrestrial ecosystems.

Adopted in 2024, the EU Nature Restoration Law builds upon existing legislation to establish a cohesive and comprehensive legal framework for the protection and restoration of nature (EU Regulation 2024/1991). This regulation defines restoration as "the process of actively or passively assisting the recovery of an ecosystem in order to improve its structure and functions, with the aim of conserving or enhancing biodiversity and ecosystem resilience, through improving an area of a habitat type to good condition, re-establishing favourable reference area, and improving a habitat of a species to sufficient quality and quantity in accordance with Article 4(1), (2) and (3) and Article 5(1), (2) and (3), and meeting the targets and fulfilling the obligations under Articles 8 to 12, including reaching satisfactory levels for the indicators referred to in Articles 8 to 12" (EU Regulation 2024/1991, Art. 3(3)).

With respect to marine and freshwater ecosystems, the EU Nature Restoration Law integrates a broad legal regime encompassing the Birds Directive (Directive 2009/147/EC), the Habitat Directive (Directive 92/43/EEC), the Water Framework Directive (Directive 2000/60/EC), the Marine Strategy Framework Directive (Directive 2008/56/EC), and the Common Fisheries Policy (Regulation (EU) 1380/2013). Notably, the Marine Strategy Framework specifies measures such as "mitigation and remediation tools", which are defined as management interventions designed to restore damaged components of marine ecosystems (Directive 2008/56/EC, Annex VI).

Article 5 of the EU Nature Restoration Law establishes the targets and obligations for Member States regarding the implementation of restoration measures for marine ecosystems. The **objective is to improve the condition of habitat types listed in Annex II of the EU Nature Restoration Law that are currently not in good condition**[8]. The specific restoration targets are as follows:

1. By 2030, restoration measures must cover at least 30% of the total area of habitat groups 1 to 6 listed in Annex II that are not in good condition, as quantified in the National Restoration Plan;
2. By 2040, this coverage must extend to at least 60%, and by 2050, to at least 90% of the area of each of the groups 1 to 6 of the habitat types that are not in good condition, as specified in the National Restoration Plan;
3. By 2040, restoration must be implemented on at least two-thirds of the percentage specified in the following point (4) for the area of habitat group 7 listed in Annex II that is not in good condition, as quantified in the National Restoration Plan;
4. By 2050, the restoration must be applied to a percentage of the area of habitat group 7 that is not in good condition – in accordance with Article 14(3) and as quantified in the National Restoration Plan.

The percentage referred to in point (4) must be defined in a manner that ensures it does not impede the achievement of maintenance of Good Environmental Status (GES), as defined under

[8] In Annex II of the EU Nature Restoration Law, marine habitat types are classified into seven groups: 1) seagrass beds, 2) macroalgal forests, 3) shellfish beds, 4) maerl beds, 5) sponge, coral and coralligenous beds, 6) vents and seeps and 7) soft sediments (not deeper than 1,000 meters of depth). To each habitat type is assigned a reference code, as specified in the Habitat Directive.

Article 9(1) of the Marine Strategy Framework Directive. Importantly, the successful implementation of the objectives set out in the EU Nature Restoration Law is intrinsically linked to the provisions and requirements of the Marine Strategy Framework Directive. In turn, the effective realization of the Marine Strategy Framework Directive's objectives is dependent on the measures and targets established under the EU Nature Restoration Law. This reciprocal relationship underscores the need for a coordinated approach to marine environmental protection and restoration, ensuring consistency in policy implementation and alignment of conservation efforts across legal frameworks.

Under the Nature Restoration Law, Member State are also required to implement restoration measures to re-establish habitat types - group 1 to 6 - in areas where these habitats are absent. These measures must be implemented on at least 30% of the additional area required to reach the favorable reference area by 2030, at least 60% by 2040, and 100% by 2050 (Regulation (EU) 2024/1991, Art. 5(2)).

The identification of the most appropriate areas for restoration measures must be grounded in the best available scientific knowledge and the latest technical advancements. This process involves a comprehensive assessment of the condition of habitat types listed in Annex II. This assessment must incorporate data reported under Article 17 of the Habitat Directive, Article 12 of the Birds Directive, and Article 17 of the Marine Strategy Framework Directive (Regulation (EU) 2024/1991, Art. 5(6)). The integration of these data sources highlights the interconnectedness of these legislative instruments, emphasizing the necessity of a harmonized approach to environmental conservation and restoration at the EU level.

Furthermore, **Member State must ensure comprehensive knowledge of habitat conditions within the following timeframes**:

1. By 2030, for at least 50% of the total area of habitat types in groups 1 to 6 listed in Annex II;
2. By 2040, for all areas of habitat types in groups 1 to 6;
3. By 2040, for at least 50% of the total area of habitat types in group 7;
4. By 2050, for all areas of habitat types in group 7 (Regulation (EU) 2024/1991, Art. 5(7)).

The EU Nature Restoration Law also emphasizes the need to enhance ecological coherence and connectivity among the habitat types (Regulation (EU) 2024/1991, Art. 5(8)).

Pursuant to the EU Nature Restoration Law, Member States are required to develop a National Restoration Plan, which must include preparatory monitoring and research to identify the necessary restoration measures (Regulation (EU) 2024/1991, Art. 14(1)). For each habitat type, Member States must quantify the current distribution and determine the areas requiring restoration, taking into consideration the variable environmental conditions resulting from climate change (Regulation (EU) 2024/1991, Art. 14(2)). Additionally, Member States are obliged to incorporate measures to achieve GES for all EU marine regions and to foster cooperation for the restoration of ecosystems that span across national borders or are part of shared marine regions or subregions, in accordance with the provisions of the Marine Strategy Framework (Regulation (EU) 2024/1991, Art. 14(14, 17)). Each Member State is mandated to submit draft of their National Restoration Plan to the EC by 1 September 2026 (Regulation (EU) 2024/1991, Art. 16).

4.7.1 Ecosystem Restoration and Vulnerable Marine Ecosystems

As defined in Article 2 of Council Regulation 734/2008, vulnerable marine ecosystems (VMEs) encompass "any marine ecosystem whose integrity (i.e. ecosystem structure or function) is, according to the best scientific information available and to the principle of precaution, threatened by significant adverse impacts resulting from physical contact with bottom gears in the normal course of fishing operations". VMEs include, but are not limited to, reefs, seamounts, hydrothermal vents, cold-water corals, and sponge beds. These ecosystems are particularly susceptible to disturbance and are characterized by slow recovery rates, or, in some cases, their inability to recover altogether.

In accordance with this legal framework, Member States are required to act based on the best available scientific evidence regarding the presence or potential presence of VMEs in the areas where their fishing vessels operate. Specifically, Member States must designate and close areas to fishing activities that involve bottom gears to prevent damage to these ecosystems. Member states must implement these closures and notify the EC upon enacting such measures. The EC, in turn, is responsible for promptly disseminating the notification of closures to third Member States, ensuring a coordinated approach to the protection of VMEs across the EU (Council Regulation 734/2008, Art. 8). This process underscores the EU's commitment to safeguarding marine biodiversity and upholding its international legal obligations to mitigate the environmental impacts of bottom-contact fishing practices (see Section 4.2 above).

In the Mediterranean and the Black Sea, deep-sea ecosystems are protected through geographically defined Fisheries Restricted Areas (FRAs), where the use of towed dredges and trawl nets is prohibited in waters deeper than 1,000 metres. These measures are considered a form of passive restoration, or unassisted recovery of deep-sea ecosystems (Da Ros et al., 2019). In this regard, emerging evidence indicates that measurable recovery of deep-sea coral communities on heavily trawled seamounts can be achieved through long-term area closures. For instance, Baco et al. (2019) suggest that recovery may occur over timeframes of 30 to 40 years. Considering this, increased prioritizations are necessary to advance the restoration of damaged VMEs.

The EU Nature Restoration Law does not explicitly mention VMEs; however, certain marine habitat types listed in Annex II, such as sponge, coral and coralligenous beds, are considered VME indicators.

4.7.2 Ecosystem Restoration as a Climate Mitigation and Adaptation Measure

Climate change is one of the most pressing global challenges, requiring a comprehensive approach that integrates data collection and analysis at large, medium, and small scales. Likewise, legal and policy frameworks at the international, regional, national, and local levels must be synergistically interconnected and effectively implemented to ensure meaningful progress in combating climate change.

The latest Intergovernmental Panel on Climate Change (IPCC) report confirms that, between 2011 and 2020, the global surface temperature increased by 1.1°C above pre-industrial levels (1850-1900) leading to widespread and rapid changes across the atmosphere, ocean, cryosphere, and biosphere (IPCC, 2023). While adaptation planning and implementation have advanced across various sectors and regions in the world, their effectiveness remains uneven, and adaptation gaps persist. Without accelerated efforts, these gaps will continue to widen as observed by the IPCC. At the same time, legal and policy measures aimed at climate change mitigation have expanded globally. However, 2024 was recorded as the warmest year to date, characterized by unprecedented land and sea surface temperatures and intensified ocean heating, with a global temperature increase of 1.55°C above pre-industrial levels, alarming the Paris Agreement's target to limit global temperature rise to 1.5°C (World Meteorological Organization, 2025). A single year exceeding 1.5°C does not indicate failure to meet the Paris Agreement's long-term temperature targets, which are assessed over decades rather than individual years. Nonetheless, every incremental temperature increase has significant consequences. Additionally, it is important to emphasize that the IPCC observed that if warming exceeds a threshold such as 1.5°C, it could be reversed over time by achieving and sustaining net negative global CO2 emissions (IPCC, 2023).

Well-aligned multilevel governance, and strong legal commitments based on the best scientific knowledge are fundamental for effective climate action. As outlined in the EU Biodiversity strategy, the biodiversity loss and the climate crisis are intrinsically linked. However, just as the crises are interconnected, so are the solutions. Ecosystems play a crucial role in combating climate change through their function of climate regulators. Nature-based solutions also represent effective strategies for combating climate change (COM/2020/380, p. 1).

The European Climate Law, adopted in 2021, aims to achieve net-zero greenhouse gas (GHG) emissions for Member States by 2050, in alignment with the long-term objectives of the Paris Agreement. This goal will be pursued through the regulation of emissions and removals, investments in green technologies, and the protection of the natural environment. To attain climate neutrality by 2050, a domestic reduction of net GHG emissions by at least 55% compared to 1990 levels is required by 2030. In line with the aim of climate neutrality, the EU is also committed to increasing its carbon sink capacity by 2030. This would involve enhancing the volume of carbon absorbed by natural ecosystems, thus contributing to the broader goal of climate mitigation (Regulation (EU) 2021/1119).

As stated in the preamble of the EU Nature Restoration Law "the restoration of ecosystems can make an important contribution to maintaining, managing and enhancing natural sinks and to increasing biodiversity while fighting climate change." The provisions outlined in the EU Nature Restoration Law serve, inter alia, to further the objectives of both climate change mitigation and adaptation (Regulation (EU) 2024/1991, Art. 1). As the EU moves forward in its climate and environmental commitments, the effective implementation of both legal frameworks – the European Climate Law and the EU Nature Restoration Law - will be instrumental in achieving a sustainable and climate-resilient future.

4.7.3 Recovery within the Nature Restoration Law

In the context of the Nature Restoration Law, the Marine Strategy Framework Directive (MSFD) and the Habitats and Birds Directives provide essential frameworks for addressing key restoration questions and guiding operational actions. These directives offer established methodologies and assessment processes that can facilitate the implementation of restoration targets. Where methodologies are not yet fully developed, they provide a basis for further scientific advancement and policy integration.

For example, Annex 2 of the Nature Restoration Law sets specific objectives for improving the condition of soft-sediment communities at depths of less than 1,000 meters that are currently degraded. This objective aligns with MSFD Descriptor 6 (D6), which states: "*Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded, and benthic ecosystems, in particular, are not adversely affected*." The interpretation of the Nature Restoration Law suggests that its objectives for soft-sedimentary habitats should align with the indicators and threshold values established for Good Environmental Status (GES) under D6. Consequently, the processes developed to establish operational indicators and define thresholds can be applied within the frameworks of both the Nature Restoration Law and MSFD D6, ensuring coherence and consistency.

Similarly, the Nature Restoration Law can build on existing work under the Habitats and Birds Directives, which determine favourable reference values for species and habitats as part of assessing favourable conservation status. These reference values define when a species or habitat is in a favourable/unfavourable state (e.g., Bijlsma et al., 2019), providing a scientific basis for restoration targets.

By leveraging these existing directives and methodologies, the implementation of the Nature Restoration Law can be integrated into broader EU conservation frameworks. Within this approach, science plays a role by providing the methodologies, indicators, and thresholds necessary to assess the condition of the marine features and support evidence-based restoration actions.

4.8 Right Holders' and Stakeholders' Involvement

Considering human societies in the context of ecosystem restoration requires a mapping from the desired ecosystem states to societal benefits. Studies considering how well policy goals such as agreed ecosystem state or fisheries targets will be reached under different management options (Fulton et al., 2014; Punt et al., 2016; Uusitalo et al., 2022), can be seen as evaluating the attainment of the society level goals. However, different stakeholder groups may prefer different ecosystem states (Schroeder, 2012; Uusitalo et al., 2020, 2023), and therefore ecosystem use, management, and restoration pathways may benefit or harm different stakeholders differently. This is an important issue in relation to the sense of fairness, having repercussions also on denizens' willingness to commit to management measures (Haapasaari et al., 2007). Particularly, the needs or preferences of the local communities or Indigenous Peoples may differ from those of recreational users, tourists or visitors, who might make up the majority of affected people in numbers.

It is important to mention that the CBD COP has adopted several important decisions and guidance on the involvement of Indigenous Peoples and local communities in decision-making processes concerning conservation and sustainable use of biodiversity. An example of one of these instruments is the Akwé: Kon Voluntary Guidelines for the Conduct of Cultural, Environmental and Social Impact Assessments Regarding Developments Proposed to Take Place on, or which are Likely to Impact on, Sacred Sites and on Lands and Waters Traditionally Occupied or Used by Indigenous and Local Communities which should be applied in conjunction with the biodiversity-inclusive EIA guidelines (CBD decision VII/16 F (2004)). Another important guidance is the Mo' otz Kuxtal Voluntary Guidelines for the development of mechanisms, legislation or other appropriate initiatives to ensure the "prior and informed consent", "free, prior and informed consent" or "approval and involvement", depending on national circumstances, of indigenous peoples and local communities for accessing their knowledge, innovations and practices, for fair and equitable sharing of benefits arising from the use of their knowledge, innovations and practices relevant for the conservation and sustainable use of biological diversity, and for reporting and preventing unlawful appropriation of traditional knowledge (CBD decision XIII/18 (2016)). In addition to several guidance developed and adopted under the CBD on the involvement of Indigenous Peoples and local communities, and incorporation of traditional knowledge in decision-making processes with their free, prior and informed consent or approval and involvement, the GBF also contains specific cross-cutting targets about this topic. For instance, Target 22 commits CBD Parties to: "Ensure the full, equitable, inclusive, effective and gender-responsive representation and participation in decision-making, and access to justice and information related to biodiversity by indigenous peoples and local communities, respecting their cultures and their rights over lands, territories, resources, and traditional knowledge, as well as by women and girls, children and youth, and persons with disabilities and ensure the full protection of environmental human rights defenders" (CBD decision 15/4 (2022), Annex, Target 22).

Targets 21 (on knowledge to guide biodiversity action) and 23 (gender equality for biodiversity action) are also cross-cutting and relevant with respect to marine ecological restoration, and they contain similar notions as those presented above.

4.9 Other Guidance, Questions and Examples of Restoration in Marine Management

Ecological restoration in terrestrial ecosystems have been more widespread than in the marine environment (Saunders et al., 2020). Marine and coastal restoration activities have focused primarily on mangroves, seagrasses, saltmarshes, kelp beds, oyster beds and coral reefs (Saunders et al., 2020). Examples of restoration in marine management include those taking place in MPAs, in habitats important for CMS listed species, in ecosystems important for carbon sinks (blue carbon ecosystems)[9] , in World Heritage Sites, among others. This section highlights some of these cases by discussing how some management tools can or cannot be used for restoration.

4.9.1 Marine Protected Areas

The commitment to effectively conserve and manage at least 30% of marine and coastal areas, especially areas of particular importance for biodiversity and ecosystem functions and services through ecologically representative, well-connected and equitably governed systems of MPAs and OECMs is contained in the GBF Target 3. As part of this continuum of restoration practices, recommended by several guidance documents, the reduction of anthropogenic pressures is one of them (FAO, IUCN, SER, 2021). It is therefore easy to see the role of MPAs in efforts to restore marine and coastal ecosystems. In the context of the EU, the Nature Restoration Law and the 2022 EU Criteria and Guidance for the Designation of Additional Protected Areas by Member States (Criteria and Guidance) highlight that: "if the restored areas comply or are expected to comply, once restoration produces its full effect, with the criteria for protected areas, those restored areas should also contribute towards the Union targets on protected areas. The Criteria and Guidance also highlight that protected areas can provide an important contribution to the restoration targets in the EU Biodiversity Strategy for 2030, by creating the conditions for restoration efforts to be successful. This is particularly the case for areas which can recover naturally by stopping or limiting some of the pressures from human activities. Placing such areas, including in the marine environment, under strict protection, will, in some cases, be sufficient to lead to the recovery of the natural values they host." (EU Regulation 2024/1991 (2024), preambular para. 10).

The 2012 IUCN guidance on protected areas restoration determines that when and where to restore ecosystems in (marine) protected areas revolves around the balance between 'need' and 'feasibility' (Keenleyside et al., 2012, p. 11). According to this IUCN guidance, the 'need' comprises the following criteria:

- One or more protected areas values falls below a certain threshold and intervention that is needed to recover them;
- Restoration helps recover a species/habitats/ecosystem of regional or national importance;
- Legal requirements are imposed; or
- Benefits to communities or co-benefits for climate change adaptation, mitigation, or other ecosystem services can be restored without compromising protected area values (Keenleyside et al., 2012, p. 11).

[9] Examples include mangroves, saltmarshes, seagrasses, kelp beds, mudflats, and several others. In addition to serving as carbon sinks (for the purpose of the UNFCCC and the Paris Agreement), these ecosystems also provide multiple other ecosystem services (e.g., coastal protection, increasing fisheries productivity, water filtration, increased biodiversity) (Diz et al., 2021).

While 'feasibility', in accordance with the IUCN guidance, is driven by the following decision-making criteria:

- Success is relatively likely;
- There is sufficient support from partners and stakeholders to ensure long-term success;
- There is sufficient available funding, resources and capacity; or
- Restoration activities are relatively cheap and easy to be undertaken (Keenleyside et al., 2012, p. 11).

Under the 2012 IUCN guidance, **successful ecological restoration in protected areas** relies on three principles:

(i) effectiveness: by re-establishing and maintaining protected area values, drawing on the original purpose and conservation and /or cultural objectives of the protected area. In doing so, consideration should be given to whether active restoration is needed, or if by removing the ecosystem pressure, the ecosystem would naturally recover. Risks of harm due to active restoration interventions should also be considered. Increasing resilience and connectivity beyond the boundaries of the protected area is also important;

(ii) efficiency: by maximising beneficial ecological, social-economic and cultural outcomes while minimising costs (and at the same time ensuring conservation goals are preserved). In doing so there is a need to ensure long-term capacity and monitoring of restoration efforts; and

(iii) engagement: by involving partners, rights holders, and stakeholders in planning and implementation. This collaboration should foster mutual learning, and ensuring that perspectives and knowledge of Indigenous Peoples and local communities (with their free prior, informed consent) are incorporated (Keenleyside et al., 2012).

An example of successful mangrove restoration in Samoa in an area that was further established as a protected area is highlighted by the GBO-5 as follows: "Samoa: The village of Vailoa is part of a large mangrove ecosystem in the Vaiusu Bay area bordering the western edge of the Apia Township. The mangroves ecosystem has been severely degraded and has decreased in size due to urban development and population pressure. The degradation of the mangroves led to significant loss of productive coastal fisheries and a filtering system for run-off into coastal waters. The Vailoa Village Council and Women's Committee established village rules to prevent further degradation of the mangrove. The United Nations Development Programme and the Global Environment Facility supported a biodiversity baseline audit, a mangrove management plan, and rehabilitation efforts. The project, which was spearheaded by the Women's Committee, resulted in the establishment of a mangrove protected area that is now the third largest in Samoa. The rehabilitation of the mangroves has replenished fish, mud crab and shellfish populations and generated income for the local community (CBD Secretariat, 2020, p. 99, box 14.1)."

Based on the above, the mutual-supportiveness between protected areas and ecosystem restoration, including in the marine environment, can therefore be summarised as:

a) Newly established MPAs can serve as a tool to stop or limit different pressures in marine and coastal ecosystems that need some degree of recovery for their integrity and functioning to be at healthy levels;

b) Restored areas need continued conservation efforts to sustain any successful restoration efforts. MPAs can play this role by actively managing, potentially preventing or minimising individual and cumulative pressures from multiple sectors on ecosystems/species included among their conservation objectives. Depending on the main threat(s), other types of conservation and management measures may suffice to prevent key threats to restored ecosystems. This could be especially the case of threats from a single sector that is effectively regulated and managed;

c) Existing MPAs can also be the object of marine ecosystem degradation, and therefore, restoration measures (passive or active) can be beneficial. Keenleyside et al. (2012) note that "previous degradation, climate change, invasive alien species and wider … seascape changes affect even well-managed protected areas… and may result in serious degradation. While the potential for restoration must not be seen as an excuse or a compensation tool for activities that damage protected areas values, it can help to reverse losses that have already occurred" (p.11).

4.9.2 Important Habitats for Convention on the Conservation of Migratory Species of Wild Animals (CMS)-listed Species

Ensuring that ecological connectivity (see Section 6) is part of ecosystem restoration activities has been recognised as a key component of successful restoration efforts to protect migratory species (UNEP-WCMC, 2024). Under the UN Decade of Ecosystem Restoration, the World Restoration Flagships initiative, which highlights best practices of large-scale and long-term ecosystem restoration, has identified the Abu Dhabi Marine Restoration initiative as one of these flagships in the marine environment (UNEP-WCMC, 2024). This initiative is restoring key coastal habitats (feeding and breeding sites) including coral reefs, seagrasses and mangroves (UNEP-WCMC, 2024, p. 51). These ecosystems serve as habitats for CMS-listed species and other migratory species, including dugongs, four species of turtles, including green turtles, three kinds of dolphins, several seabird species, among others (UNEP-WCMC, 2004; see also UN Decade on Ecosystem Restoration, n.d.).

4.9.3 Marine and Coastal Wetlands

Marine and coastal wetlands comprise ecosystems such as mangroves, lagoons, seagrass beds, saltmarshes, estuaries, tidal flats, kelp forests and coral reefs (Convention on Wetlands, 2021). As seen in Section 4.5 above, the Ramsar Convention on Wetlands has deliberated on restoration of wetlands. One of the guidance developed under the Convention is the Integrated Framework and guidelines for avoiding, mitigating and compensating for wetland losses (also known as the 'avoid-mitigate-compensate framework') (Ramsar Convention Resolution XI.9, 2012). Under this Framework, restoration would fall under the mitigation or compensation actions (see Figure 4.1).

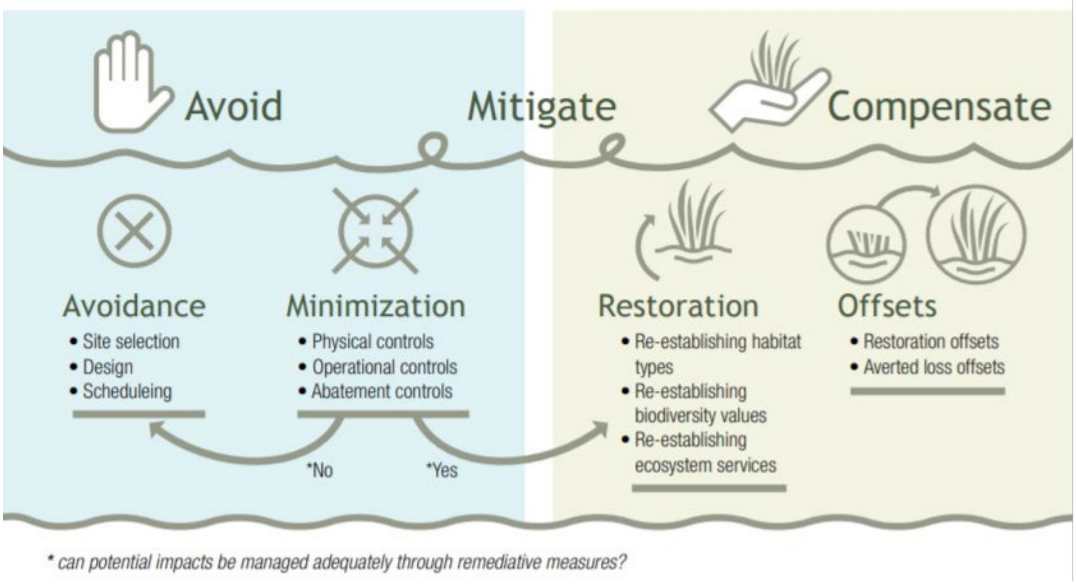


Figure 4.1. Ramsar Convention avoid-mitigate-compensate framework. Source: Convention on Wetlands (2021), p.2.

Examples of successful coastal and marine wetlands restoration under the Ramsar Convention include the Manglares de Nichupté Ramsar Site in Cancun, Mexico which had suffered intense pressures from tourism (Convention on Wetlands, 2021) through the following interventions, inter alia:

- Planting over 69,000 mangrove specimens;
- Hydrological restoration to enable reforested areas connectivity with the Nichupté Lagoon System through canals; and
- Controlling an invasive species - *Casuarina equisetifolia* – by removing 7,600 specimens from 11.1 hectares of the Ramsar Site (Convention on Wetlands, 2021).

Another successful example includes the restoration of seagrass beds in the Tampa Bay Estuary in Florida by introducing limits on nitrogen inputs to the bay, including through prohibitions of sale and use of fertiliser during rainy season and stricter coastal zone development regulations (Convention on Wetlands, 2021).

4.9.4 World Heritage Sites

World Heritage Sites, listed under the World Heritage Convention, can include natural sites (marine and terrestrial) if, among other things, the criteria of outstanding universal value (OUV) is met (Convention Concerning the Protection of the World Cultural and Natural Heritage, Art. 2).

An example of restoration measures adopted for a coastal World Heritage Site under this Convention, is the Everglades National Park. The Everglades National Park (Florida, US) was inscribed on the World Heritage List in 1979 due to its wetlands of global importance (Douvere, 2015). The Park is part of a larger ecosystem that has been altered throughout the years through water control systems, agricultural practices, and urban development (Douvere, 2015). As a result of such pressures, in 2010 the Everglades National Park was included on the List of World Heritage in Danger, which in turn enabled the mobilisation of funds for restoration projects with a view to ensure term long-term protection of the site (Douvere, 2015).

4.9.5 Coral Reefs Technical Guidance as an Example of Implementation of CBD Priority Actions on Coral Reefs

Coral reefs' restoration has been the object of several projects globally, and in response to a call from UNEA-4 to UNEP and the International Coral Reef Initiative (ICRI) to identify best practices in this field, a guide was published by UNEP in 2020 (Hein et al., 2020). The report and a subsequent policy brief highlight the findings of IPCC that up to 90% of coral reefs could be lost by 2050 even if warming is limited to 1.5°C above pre-industrial levels as called for under the Paris Agreement (UNEP and ICRI, 2021). These documents note that coral reef restoration does not succeed if the threats to the reef systems are not mitigated, and defines coral reef restoration as "a suite of active interventions aimed at improving reef structure and ecosystem function and increasing populations of key species" (UNEP and ICRI, 2021, p. 2). Examples include: **direct transplantation of coral fragments** on the reef, coral gardening, larval propagation, and the use of artificial structures with planted coral (UNEP and ICRI, 2021). For best chance of success, a range of continued proactive and reactive activities are recommended (see Figure 4.2) (UNEP and ICRI, 2021).

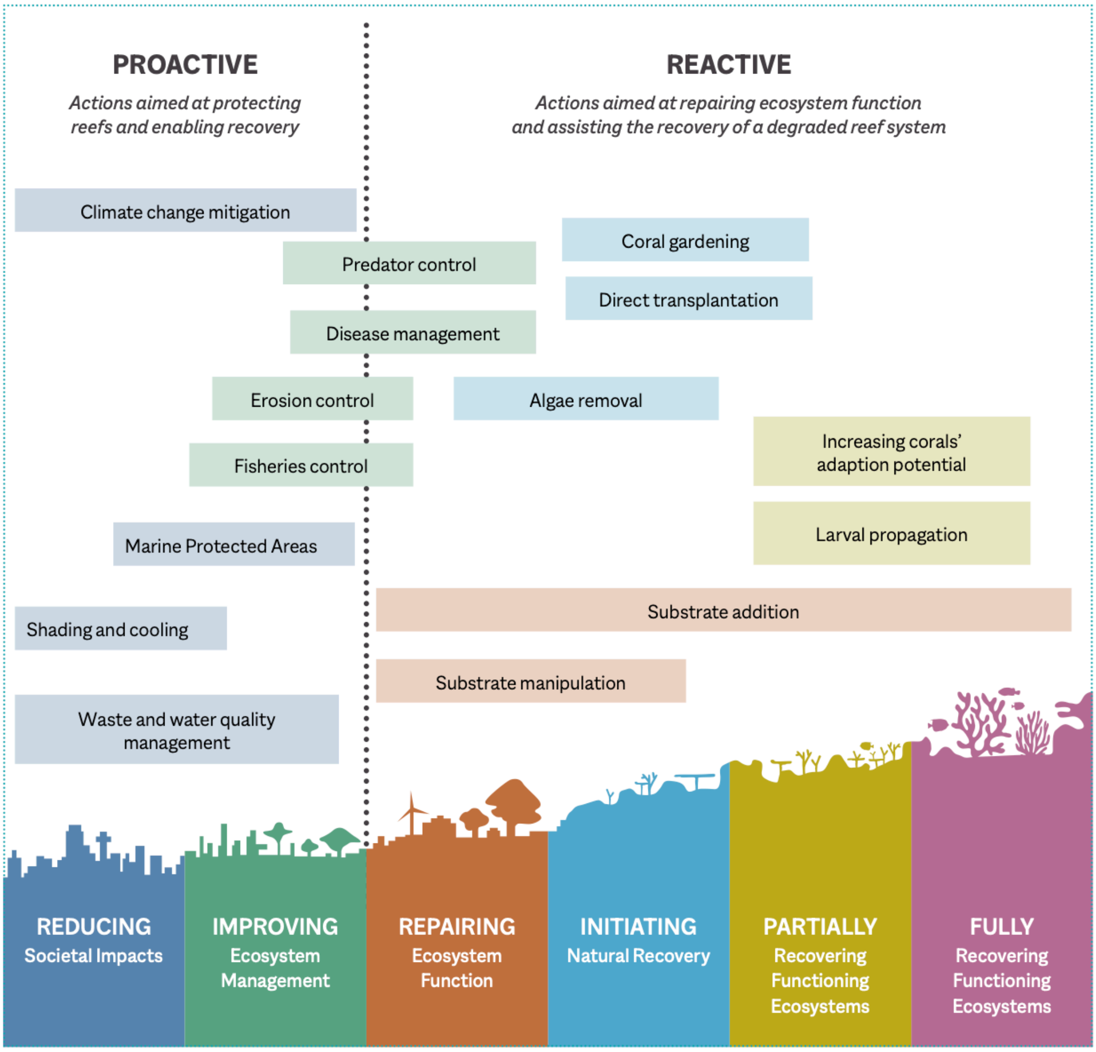


Figure 4.2. Continuum of proactive and reactive interventions for coral reef restoration recommended by UNEP and ICRI (2021). Source: UNEP and ICRI (2021).

For enhanced chance of effectiveness, it was also recommended that coral reef restoration projects: 1. integrate strategies to abate threats; 2. incorporate climate change impacts projections, as well as site vulnerability; 3. consider when selecting sites and methods the prevalence of disease, physical integrity of the reef, population connectivity of key species; 4. engage with stakeholders and maximise socio-economic benefits to local communities; and 5. implement monitoring systems for adaptive management (UNEP and ICRI, 2021).

Examples exist from coral reef restoration were methods to achieve social-economic, ecological and climate goals are assessed together in a more integrated approach (Figure 4.3).

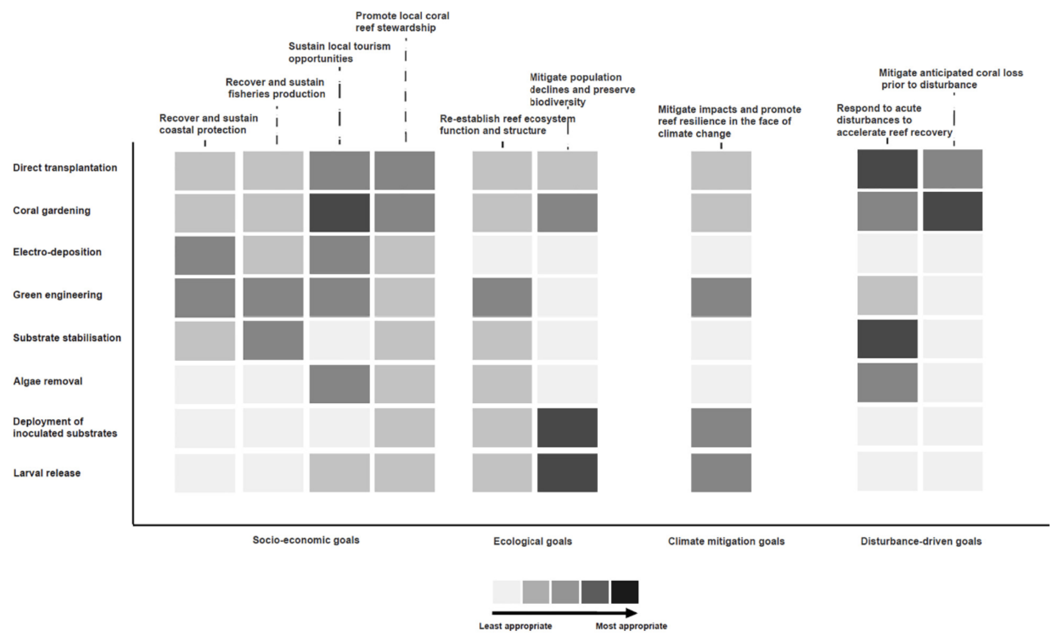


FIGURE 2 | Method suitability matrix for each coral reef restoration goals. The darker the color, the more appropriate a method is to each specific goal. Note that for many goals multiple methods may be suitable.

Figure 4.3. Source: Figure 2 of Hein et al., 2021 (https://doi.org/10.3389/fmars.2021.618303) showing the relationship if different restoration methods with specific goals.

4.9.6 Outstanding Questions to Make Policy Operational

This Section 4 outlines the overarching policies and targets for nature restoration. These policies and targets analyzed herein focus on improving the structure and function of species and habitats, aiming to enhance the condition of those currently not in a good condition (ecological state). Several questions arise when translating these policy objectives and targets into operational actions:

- **What is the target state for restoration?** Defining the desired ecological condition, function or baseline state that restoration efforts should aim to achieve with a sense check on historical presence vs suitability of environment related to factors other than human impacts (i.e. climate change induced impacts).
- **What are the reference conditions of the species or habitats requiring restoration?** Establishing scientifically grounded benchmarks based on historical data, ecological studies, and expert assessments. Consider a shifting baseline as environments constantly change due to both natural and anthropogenic reasons.
- **What pressures need to be considered?** Identifying and accounting for cumulative and site-specific stressors, such as climate change, pollution, and human activities. Consider both the present and future pressures and avoid solely examining the pressures that are relatively easy to quantify.
- **What is the current state, what was the past state, and how close do we need to get to the past state to achieve "good condition"?** Understanding historical baselines and spatial variations to inform restoration strategies and ensure effective ecological recovery. Consider unintended consequence of re-establishment of habitats as well as accounting that ecosystems may reach a new level of equilibrium which might not be the same as the past.

4.10 Conclusions

Global international policy frameworks have established goals and targets on marine ecosystem restoration. Among these, the Convention on Biological Diversity Kunming-Montreal Global Biodiversity Framework is a prominent global policy that aims at halting and reversing biodiversity loss. Furthermore, CBD COP has recognised that the GBF is a contribution to the achievement of the 2030 Agenda for Sustainable Development (and its SDGs). The prominence of the GBF derives from the fact that the CBD is a quasi-universal treaty comprised of 196 Parties. All UNCLOS Parties are Parties to the CBD. UNCLOS establishes absolute obligations on States to protect and preserve the marine environment, including by taking necessary measures "to protect and preserve rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life" (UNCLOS, 1982; Art. 194(5)). ITLOS, on its Advisory Opinion on Climate Change and International Law, has stated that the obligation to preserve the marine environment may include the obligation to restore marine habitats and ecosystems to regain ecological balance. In order to interpret these corresponding obligations, it is necessary to conduct a systemic interpretation of different instruments due to the fact that specific terms are dispersedly defined therein. For instance, 'ecosystems' and 'habitats' are defined under the CBD, and not by UNCLOS.

Furthermore, guidance on ecosystem restoration applicable to the marine environment is contained in several global policy instruments, including under the CBD with a view to restore at least 30% of degraded marine and coastal ecosystems by 2030:

- The CBD Action Plan for Ecosystem Restoration;
- The CBD Priority Actions for Coral Reefs;
- The CBD Workplan on Coldwater Areas;
- The CBD Programme of Work on Marine and Coastal Biodiversity;
- The CBD biodiversity-inclusive EIA/SEA guidelines.

Despite the existence of several guidance instruments under the CBD on ecosystem restoration, the CBD COP 16 identified marine and coastal restoration as an area that would benefit from further attention under the Convention (CBD decision 16/17 (2024), Annex, para. 1(a)).

When focusing on marine and coastal restoration, it is important to also consider several recommendations and guidance under other instruments, such as the CMS, the Ramsar Convention, as well as obligations under the UN Fish Stocks Agreement and the BBNJ Agreement (once it enters into force), among others. Importantly, the CMS has also adopted a Strategic Plan 2024-2032 for migratory species, which inter-relates to the GBF (see Table 4.2).

These instruments include commonalities, which in turn, contribute to policy coherence. Common components of ecosystem restoration include: reference to the ecosystem approach as a basis for restoration activities (which should include considerations on, inter alia, species interactions/food webs; important habitats for biodiversity, life-history stages of species, and threatened or endangered species; areas important for biodiversity; areas important for biological productivity; ecological connectivity; ecosystem integrity (i.e., ecosystem structure and function); and resilience in light of multiple pressures (including from climate change and ocean acidification). Several of these components have been incorporated into EBSA descriptions globally (and in several instances, EBSA descriptions have also incorporated areas identified as VMEs), pointing to a potential prioritisation exercise.

At the global level, explicit policy objectives are not commonly set up (as opposed to legal instruments). Goals, visions and missions may be a proxy for objectives, as well as wording such as "in order to" or "with a view to" (which are more commonly established at the national/regional levels, where specific habitats or species are identified). However, certain global-level processes can be very useful in guiding prioritisation of specific species and habitats. For instance, the CBD EBSA process and EBSA descriptions, the FAO/RFMO VME identification processes (and requirements to avoid SAI – or how to restore habitats that have suffered SAI); the CMS listed species; wetlands under the Ramsar Convention (which are also important for the UNFCCC and the Paris Agreement as carbon sinks (UNFCCC, Art. 4(1) (d) and Paris Agreement, Art. 5). Policy guidance adopted under these treaties, supplemented by technical guidance by authoritative bodies (e.g., IPCC, IPBES, IUCN, ICES, etc) can support implementation of global targets on marine ecosystem restoration in much more detail than the high level language contained in the targets. Table 4.2 below aims to summarise key goals, targets (and their respective timeframes) in relation to these identified essential components of marine and coastal ecosystem restoration. This chapter assessed several other instruments, including guidance instruments and legal frameworks, not covered in this summary table. Table 4.2 below focuses only on the policy or legal instruments that have established specific timeframes applicable to marine and coastal ecosystem restoration. It is therefore recommended that it is read together with the respective sections of this chapter for a more comprehensive picture of international policy and guidance applicable to marine and coastal restoration.

Table 4.2. Summary of how different targets/objectives/timeframes/and common components of restoration that need to be taken into account (e.g., food webs, habitats, biodiversity, productivity, ecological connectivity, and ecosystem integrity (structure and function).

Policy or Law	Restore what?	Five elements when restoring ecosystem integrity (structure and functioning) and services					Remarks	Timeline
		Food web	Habitat	Biodiversity	Productivity	Connectivity		
UNGA SDG 14.2	Resilience Health Productivity	yes	yes	yes	yes	no	“Healthy and resilient” implies a functioning food web, with representative habitats and biodiversity.	2020 (originally). Now, 2030 as part of the broader 2030 Agenda
CBD GBF Goal A	Integrity Connectivity Resilience of all Ecosystems	yes	yes	yes	yes	yes	Same as above. Also note that in marine and coastal biodiversity decisions of the CBD, climate change and ocean acidification refugia sites have been identified as important sites to ensure resilience.	2050
CBD GBF Target 2	Biodiversity; Ecosystem functions and services; Ecological integrity; Connectivity.	yes	yes	yes	yes	yes	Target 2 does not require restoration be completed by 2030, but that at least 30% of degraded coastal and marine ecosystems are under effective restoration.	2030
CMS Strategic Plan 2024-2032 Vision Statement	Migratory species; Connected habitats.	yes	yes	yes	possibly yes (although not explicit)	yes	Habitats under the CMS are defined as any area in the range of a migratory species that contains suitable living conditions for that species.	2032
CMS Strategic Plan 2024-2032 Goal 2	Habitats; Ranges of migratory species; Connectivity.	yes	yes	yes	Possibly yes, but not explicit	yes		2032

Policy or Law	Restore what?	Five elements when restoring ecosystem integrity (structure and functioning) and services					Remarks	Timeline
		Food web	Habitat	Biodiversity	Productivity	Connectivity		
CMS Strategic Plan 2024-2032 Target 2.1	Functionality; Ability to support migratory species throughout their life cycles.	yes	yes	yes	yes	yes	The action here is to identify, assess, and monitor all habitats of CMS-listed species	2029
CMS Strategic Plan 2024-2032 Target 2.2	Habitats for CMS-listed species	yes	yes	yes	yes	yes	The means to achieve the protection and restoration of such habitats under Target 2.2 is through ecologically representative, well-connected and equitably governed systems of protected areas and OECMs	2032
EU Nature Restoration Law	Ecosystems; Habitats; Species; Biodiversity; Resilience (incl. to climate change).	yes	yes	yes	yes	yes	Several timeframes are established between now and 2050. For instance, by 2030, restoration measures must cover at least 30% of the total area of habitat groups 1 to 6 listed in Annex II that are not in good condition, as quantified in the National Restoration Plan. By 2040, this coverage must extend to at least 60%, and by 2050, to at least 90% of the area of each of the groups 1 to 6 of the habitat types that are not in good condition.	2050

5 Methods to Model and Measure the Recovery Rate and Recovery Times of Marine Habitats and Species

The aim of this chapter is to summarise available methods to model and measure the recovery rate and recovery times of marine habitats and species, including data/parameter, requirements strengths and weaknesses, engaging with as wide as possible representation of ecosystem components i.e. fish, marine mammals, benthos, birds, as well as considering "ecosystems" as a whole, such as trophic interactions. For the full text of the relevant terms of reference, see Annex 2, ToR a) and ToR b).

Key Messages

- Restoration is only possible if the pressure(s) that caused the degradation is removed or mediated and the physical environment is in a suitable condition.
- Restoration timelines for many species, habitats and ecosystem features are much longer than the timeframes over which the success of policy is evaluated.
- In degraded marine environments, hysteresis [the existence of different stable states under the same variables or parameters] can prevent a system from naturally returning to its original state even after stressors are removed.
- Many different factors limit the success of restoration in marine ecosystems. Each needs to be accounted for. Suitable habitats are the key; species cannot recover in areas where the habitat is not suitable.
- Recovery rates are highly variable for species and habitats. Monitoring should match the spatial/temporal scale of the key habitat features and/or target species (e.g. life-history characteristics of the species).
- Targets, goals and objectives of the restoration objectives need to be clearly defined. The monitoring program should ideally be developed based on the response variables and selected monitoring methods appropriate to achieve the recovery objectives.
- The distributions and population dynamics of habitats and species that have undergone severe distribution contractions may not be suitable to inform their restoration.
- Assessments of statistical power or appropriate monitoring to detect recovery of species, functional groups and/or ecosystem components are lacking in many cases.
- Predictive modelling is currently the only available practical tool for assessing recovery times at the scale of entire habitats and ecosystems.
- To predict recovery accurately, mechanistic models are essential. Monitoring the interactions between the response variable and the environment is crucial to account for the non-stationarity of model parameters as these may be subject to substantial change into the future, i.e., climate, species interactions.

5.1 Factors Affecting Recovery Rates

The overall objective of marine restoration is to achieve a situation where target habitats and species are self-sustaining. In other words: it should not be necessary to undertake maintenance through human interventions for the target habitat or species to sustain itself. In the sections below, a series of factors that can affect the success of marine nature restoration attempts is described. Although they are discussed in isolation, these factors can interact in several ways, often making restoration to a self-sustaining situation more difficult than when these would not interact. A single factor may limit the success of restoration even if all other factors are favourable.

This particularly applies to restoring marine habitats, as defined in Annex II of the EU NRL, since the interaction between factors may be strong and lead to 'tipping points' and hysteresis in state-pressure relationships, and delays in recovery. An example is the restoration of seagrass where several of the drivers discussed below can be limiting the success of restoration: for example, one needs healthy seagrass which is genetically adapted to the specific local conditions for individual plants to do well, but also a minimum density and area (i.e., the tipping point in this case) to allow a seagrass meadow to create the physical and biological conditions in which seagrass can sustain itself and self-recruit.

Therefore, previous existence of a habitat type in an area may be an indication of the restoration suitability of the habitat in this area, but the current circumstances will probably be very different from when it was historically present. Hence, careful measuring and analysis of the way in which the factor outlined below interact in a specific location is required to determine the likely success of a restoration effort there and, if it is considered feasible, how to plan it (see further Section 5.1.7).

Role of hysteresis in marine restoration

In ecology, hysteresis refers to the dependence of an ecosystem's state on its history, meaning that once an ecosystem undergoes a change—often due to external disturbances like habitat degradation, climate change, or species loss—it may not return to its original state even if the initial abiotic conditions are restored (Litzow and Hunsicker, 2016). This phenomenon is crucial in understanding ecological resilience and regime shifts. Hysteresis in marine restoration can result in the delayed or non-linear response of ecosystems to changing environmental conditions and restoration efforts. In degraded marine environments, such as overfished coral reefs or seagrass beds affected by eutrophication, hysteresis can prevent a system from naturally returning to its original state even after stressors are removed (Blackwood et al., 2012; Cardoso et al., 2004). This phenomenon occurs due to feedback mechanisms, such as altered species interactions, nutrient cycling shifts, or changes in habitat structure that create alternative stable states. For example, once a coral reef has transitioned to an algal-dominated state, the absence of herbivorous fish and continued sedimentation can reinforce algal persistence, making coral recovery difficult without intervention. Understanding hysteresis is essential for designing effective marine restoration strategies, as it highlights the need for targeted actions, such as reintroducing key species or modifying physical conditions, to overcome ecological thresholds and promote system resilience (Sheaves et al., 2021).

Examples of empirical drivers of recovery rates

We conducted a preliminary review of studies that quantify recovery rates and categorized the information based on the Marine Strategy Framework Directive (MSFD) broad habitat types and species groups. The recovery times of marine ecosystems and species varied significantly, ranging from a few weeks or months to several decades. This difference in recovery times can be linked to a number of factors, namely whether rehabilitation, passive or active restoration is carried out, whether individual species or entire habitats are the focus of the studies, and indeed which habitats are explored. It is highly dependent on the temporal and spatial scale which is reported; one of the biggest knowledge gaps which currently exists is the lack of long-term studies of restored habitats with most information relating to projects of < 5 years (Borja et al., 2010). A large body of work has been completed in the USA but is comparatively lacking in Europe and is a knowledge gap which needs to be addressed in order to better understand the drivers and timescales associated with restoration. In addition, there is a significant bias towards taxa which are studied, for example most studies to date have focused on plants, invertebrates and fish, with mammals, amphibians and reptiles rarely the focus (Debue et al., 2022). Recovery rates also greatly depend on the ecosystem function evaluated, restoration method and regional variation (Su et al., 2021). Studies are often based on short term evaluation, whereby impacts to short-lived species or early colonizers are known more than for longer-lived and slow-growing species.

Recovery in benthic ecosystems depends on the type of disturbance, the level of degradation experienced within the ecosystem, and the habitat type in question. In many circumstances recovery can take less than 5 years for estuarine and coastal ecosystems especially when focusing on biota which have a relatively short lifespan or high reproduction rates, however, recovery to attain complete ecological functioning from a fully degraded ecosystem can take a minimum of 15-25 years (Borja et al., 2010). Benthic sediment habitats can recover from fishing-related damage within days to over eight years, although this does depend on the type of benthic fishing gear primarily used prior to restoration (Foden et al., 2010). Saltmarshes can start to show signs of recovery and comparability to reference habitats within 10 years (Able et al., 2008). Mangroves typically recover in 10–20 years, but can take up to 40 years to reach comparable biomass levels of undisturbed mangroves (Su et al., 2021). Seagrass meadows are highly sensitive to physical and chemical disturbances and can therefore take decades to recover, although early signs of recovery may appear within a few years if stressors such as eutrophication are reduced or removed (Fonseca et al., 1998). Similarly, macroalgal communities may start to partially recover within the first year after planting, however, recovery can take over 10 years to achieve recovery of a full macroalgal forest (Bianchelli et al., 2023; Galobart et al., 2023). Biogenic habitats, such as kelp forests and oyster reefs, can recover in under 10 years, but often only with active restoration. In some cases, recovery remains absent for over 70 years without active restoration.

Pelagic ecosystems face various disturbances, and recovery times are uncertain. Reducing pollution can restore ecosystems within decades, but broader ecosystem recovery is often difficult to achieve. Food web changes caused by disturbances can be particularly challenging to reverse.

The recovery rates of marine species also vary widely. There are limited examples of recovery rates of marine mammals after passive or active restoration within Europe. Turtles generally recover well with conservation efforts, increasing up to 13.9% annually, though full recovery is slow. Birds show rapid reproductive improvements following invasive species removal, but long-term recovery timelines are unclear. Fish stock recovery differs by species; in many cases fish assemblages start to be comparable to adjacent natural counterparts within 1-2 years (Lechêne et al., 2018); and there is evidence that shark populations can exhibit rapid increases in abundance and trophic structures within 8 years, exceeding model estimates (Speed et al., 2018). However, for many over-exploited marine fish, even 15 years after restoration efforts are made, recovery response may be limited (Hutchings, 2000).

Overall, many marine species and ecosystems take decades to centuries to recover from disturbances, often requiring active restoration, as seen in oyster reefs. However, restoration provides essential habitats for many species even when it has not achieved fully comparable ecological functioning. Achieving the ambitious goals of the MSFD and the Nature Restoration

Regulations—including restoring 30% of habitats by 2030—will depend on such efforts. To support this, the Joint Research Centre is developing a comprehensive catalogue of effective restoration techniques, initially focusing on seagrass and oyster reefs, to help Member States meet their targets and enhance marine ecosystem health. The long-term goal is to expand this initiative across all habitats, providing a crucial resource for restoring and preserving Europe's marine ecosystems.

Exploration of the drivers of the recovery rate of benthic invertebrates

A preliminary analysis by Dr. J.G. Hiddink (Bangor University, UK) of empirical estimates of passive recovery after cessation of disturbance for benthic invertebrates evaluated what the drivers of the recovery rate are for marine benthic invertebrates. Abundance and biomass estimates were collated for studies for benthic habitats for all substrates where recovery after cessation of disturbance or introduction of new substrates for both species and communities were recorded (Figure 5.1). Logistic population growth curves were fitted through these time-series to estimate the logistic population growth parameter *r* from 64 sources, with multiple time-series present in many of the sources, yielding a total of 255 *r* estimates (Figure 5.2). The recovery rate *r* can be used to estimate the time to recovery (Figure 5.2) and is required when modelling recovery times.

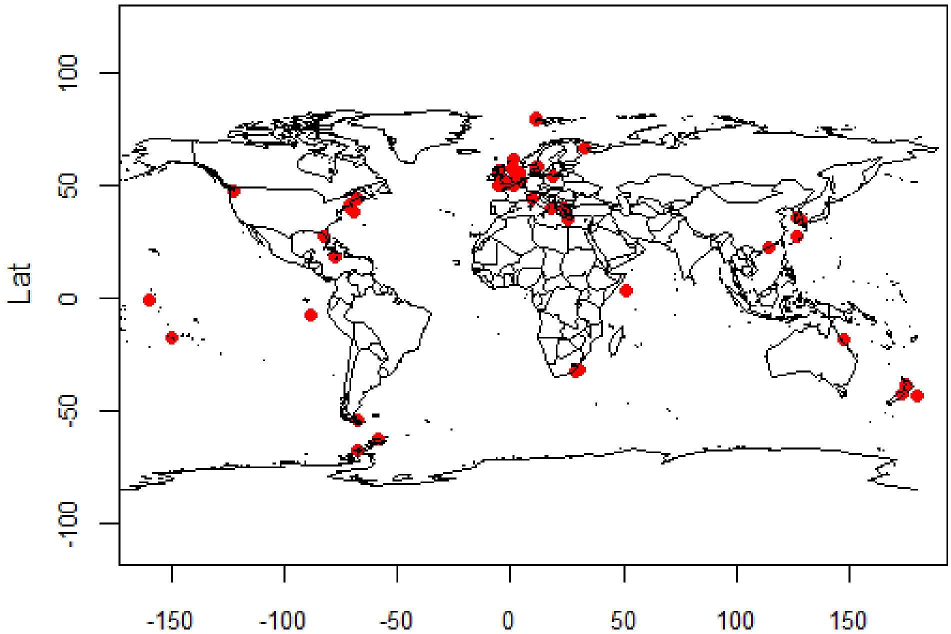


Figure 5.1. Global distribution of the included datasets in the study by J. Hiddink.

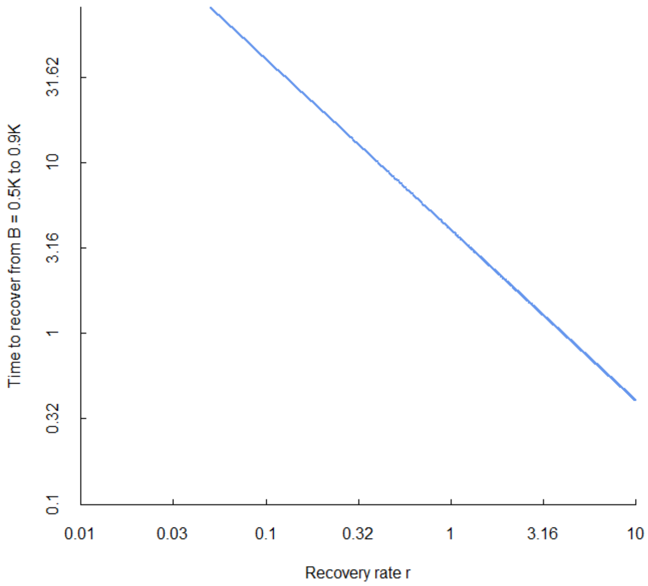


Figure 5.2. Theoretical relationship between the instantaneous recovery rate *r* and the time needed for recovery from 0.25K to 0.95K, where $\log_{10}$(time to recovery) = 0.607 – $\log_{10}$(r).

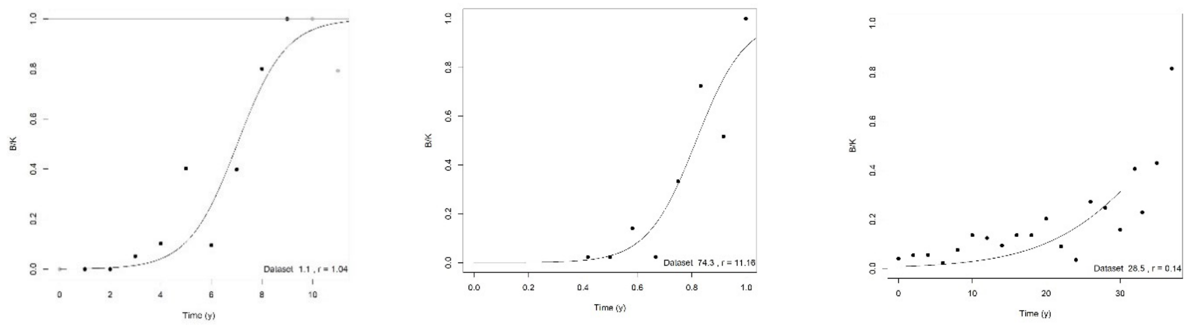


Figure 5.3. A few examples of datasets with fitted recovery curves are shown to illustrate the process used to estimate these recovery rates. The results of this analysis show that a very wide range of *r* estimates was obtained in this analysis, ranging from 0.1 to >100, implying recovery times ranging from decades to weeks. On average recovery rates were higher on soft (sedimentary) than on hard (artificial, rocky) substrates ($F_{1,254}$= 26.8, p < 0.0001) decreased with depth ($F_{1,254}$= 26.9, p < 0.0001) and the size of the intervention ($F_{1,254}$= 7.9, p = 0.005) the resulted in recovery (Figure 5.4). Therefore, faster recovery is predicted in shallower water, for soft bodied, and for smaller interventions, with slower recovery in deep water, for large areas and hard bodied fauna.

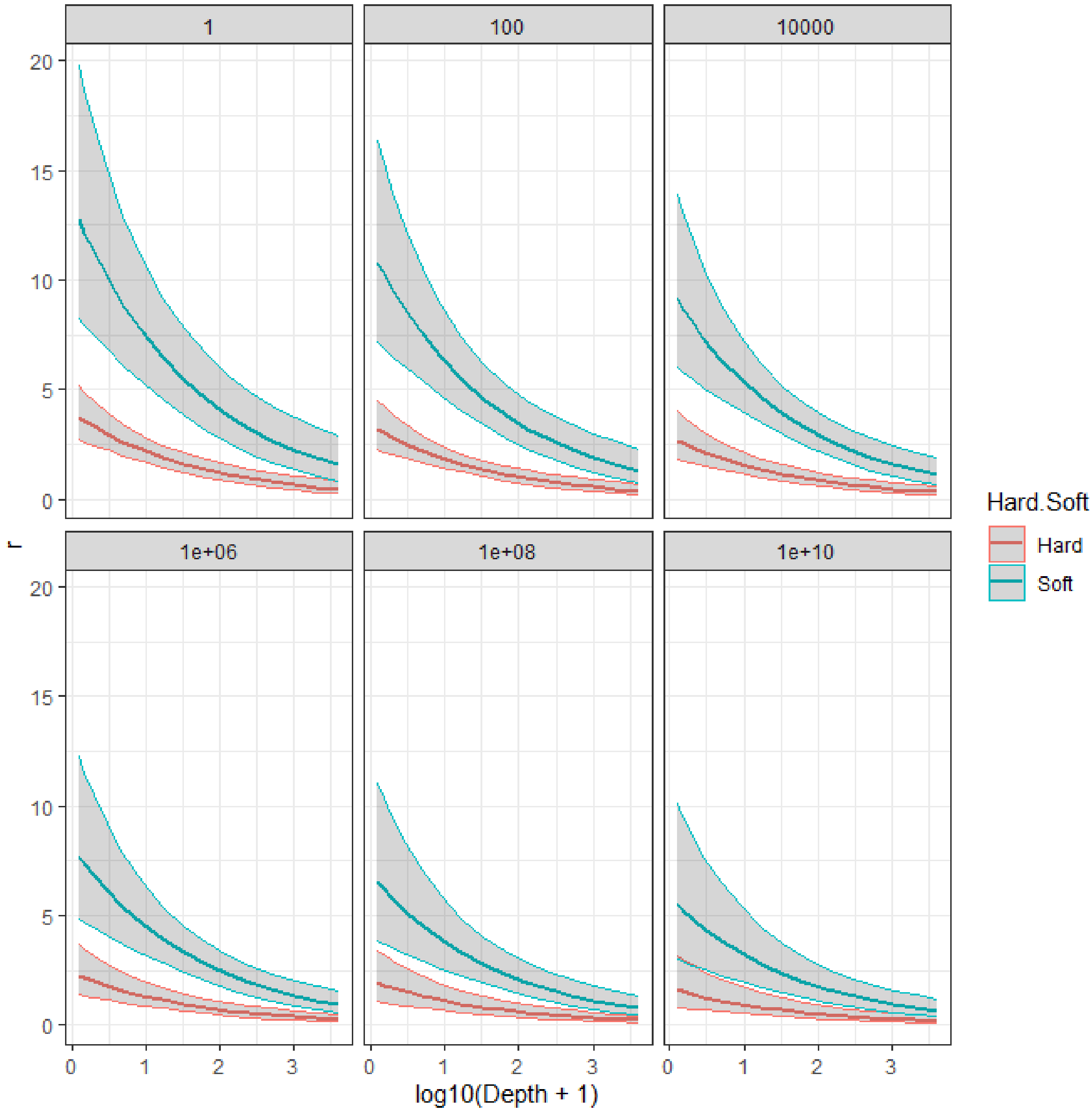


Figure 5.4. Predicted recovery rate *r* in benthic species and communities for different depths and soft and hard substrates and different sized areas. The six panels indicate the size of the intervention in m², ranging from 1 m² to 10000 km².

For the time series analysed, 50% would recover in < 2 years, and 75% < 5.7 years, However, 5% would need > 18.4 years to recover.

5.1.1 Recruitment Rates

Recruitment generally refers to the introduction of new individuals into a population, e.g. birth of offspring (e.g. birds or mammals) or arrival and transition of larval organisms (such as fish or corals) from the planktonic stage to settlement in a habitat where they mature. Recruitment rates play a crucial role in the recovery of marine ecosystems, as they determine the supply of new individuals that can repopulate recovering habitats. High recruitment rates can accelerate ecosystem recovery, while low recruitment rates can delay or even prevent recovery, particularly in systems where larval dispersal is limited or where environmental conditions inhibit settlement and survival. For example, reef systems with abundant planulae and coral cover can recover within a decade, while those with significantly fewer planulae may take decades (Kojis and Quinn, 2001). Although many marine species have a planktonic egg and larval stage, some species lack such widely-dispersing stages and develop directly, for example, benthic juveniles hatch from benthic eggs in some species of nudibranchs and octopus. If a species has been locally extirpated, such direct development is likely to result in very slow recovery. For many species of cold-water corals, recruitment can be episodic, and driven by ocean circulation (e.g., Thresher et al., 2011). Restoration strategies may seek to enhance recruitment through techniques like larval seeding, artificial reefs, or translocation of juveniles to improve accelerate ecosystem regeneration.

5.1.2 Life-History Characteristics

Understanding the life-history characteristics of marine species is essential for designing effective restoration and recovery strategies. Aligning restoration efforts (both passive and active) with the ecological needs and reproductive strategies of the target species assemblages, is essential to ensure restoration project success. The r-K continuum is a fundamental concept in life-history theory, particularly relevant in marine ecology. It describes the spectrum of reproductive strategies that species adopt in response to a range of environmental pressures and conditions. The r-K selection theory was initially proposed by ecologists Robert MacArthur and E.O. Wilson in the 1960s (MacArthur and Wilson, 1967) and further elaborated by Pianka (1970). It defines a set of species life-history characteristics along an r-K selection continuum (Table 5.1) where r-selected species tend to favour unpredictable or disturbed environments where their ability to reproduce and grow quickly is advantageous; by contrast K-selected species are adapted to more stable environments where competition for resources (such as space) is intense and inter-species interactions become more important in determining the climax assemblage state. It can therefore be expected that r-selected species will respond much more rapidly to restoration than K-selected species.

Table 5.1. Set of life-history characteristics along an r-K continuum.

Marine Species Life-History Characteristics	r-Selected	K-Selected
Reproductive rate	Frequently produce a large number of offspring.	Low and/ or unpredictable reproductive rates with fewer offspring
Age of maturity	Reach reproductive age quickly.	Slower growth and later maturity.
Longevity	Tend to have shorter lifespans (months - years)	Relatively long lifespans (many decades)
Parental care	Little to no parental care	Offspring receive significant parental care.
Mortality rate	A significant proportion of offspring do not survive to adulthood	A higher proportion of offspring survive to adulthood.
Individual body size	Tend to be relatively small (centimetres or less)	Tend to be relatively large (>10s of centimetres to 10s of metres)

5.1.2.1 Recovery of vulnerable marine ecosystems (VMEs) from impacts of bottom contact fishing gear

Species with greater and often extreme longevity, slow growth rates, and episodic recruitment, such as habitat-forming corals and sponges, are particularly slow to recover. Deep-sea species that meet the FAO criteria (FAO, 2009) for identification of vulnerable marine ecosystem (VME) indicators, share these characteristics. Many of these species live on the continental slopes and seamounts in deep waters where deep-sea fisheries are prosecuted. To date, there is no evidence of fishing-impacted seamount communities regaining their pre-disturbance condition in terms of species diversity, ecosystem functioning, megafaunal abundance, or community composition over decadal time periods (Althaus et al., 2009; Williams et al., 2010; Malecha and Heifetz, 2017; Clark et al., 2019; Dinwoodie, 2021a,b; Last et al., 2019a,b; Goode et al., 2020). In the south-west Pacific, coral patches damaged by fishing are estimated to require over 100 years for full recovery (Probert et al., 1997). However, the first step towards ecosystem recovery has been observed on former precious coral fishing grounds on the Emperor Seamount Chain where forty years after trawling ceased, recruitment has been observed at some relatively shallow sites (300 to 600 metres) (Baco et al., 2019).

5.1.3 Genetic Diversity

When planning restoration actions, it is crucial to aim at reintroducing self-sustaining populations that are demographically stable and genetically resilient, ensuring their long-term viability and adaptability to future environmental changes. Ecosystems and species depend on genetic diversity for resistance and resilience to natural changes and anthropogenic impacts. It constitutes one of the three biodiversity pillars. Thus, protecting and restoring genetic diversity is key to conserving and restoring species and ecosystems, as well as the services they provide to people (O'Brien et al., 2025).

Although only "genetic exchange" is mentioned in Annex VII of the NRL, with no mention of "genetic diversity" or "within species diversity" or "intraspecific diversity", the Convention of Biological Diversity (CBD) describes biodiversity as "every species and all the genetic differences within each species". These genetic differences contain variation between individuals and populations, which determines their potential to respond to pressures through adaptation and, thus, the fitness of individuals and their populations. Hence, genetic diversity is essential to establish and maintain self-sustainable populations and ecosystem stability and functions. Thus, including genetic diversity in restoration plans is relevant for both biodiversity conservation and for securing long-term success of the restoration.

Species, and therefore, ecosystem resilience, i.e., the ability to return to their reference conditions after a perturbation, are key features to consider for ecosystem stability and to the success of restoration in the long term, going beyond only initial establishment. Thus, the effectiveness of a restoration action would be enhanced by incorporating within-species and inter-species genetic diversity (O'Brien et al., 2025).

One aspect to consider is the geographic source of material to be used in the (re)introductions (provenance) as the genetic diversity of such initial pool and its adaptation to local circumstances will be critical to the survival and adaptability of restored populations elsewhere (Wood et al., 2024).

Another aspect is increasing the genetic diversity of ecologically important species in an ecosystem, aiming at increasing the buffering capacity of the whole community. This would reduce inbreeding and genetic loss and provide greater diversity in traits, contributing to functional diversity and ecosystem complexity. As a result, the whole community would benefit, allowing more species to coexist (increased community diversity) and improving ecosystem services, such as carbon sequestration and fisheries (O'Brien et al., 2025).

Restoring gene flow between populations should also be considered, improving general connectivity across habitats by genetic exchange and reduced inbreeding. Enhancing ecosystem connectivity is part of KM-GBF Goal A and central to NRL. Assessing the genetic diversity prior to and during restoration can give information on the degree of habitat fragmentation, help to identify priority locations for habitat restoration to safeguard genetic diversity (select target location and input material), and to monitor the success of the restoration of ecosystem connectivity. Including genetic diversity in the national assessment of each habitat would be beneficial to ensure the adaptability of populations of species, improve the resilience of ecosystems, and monitor the success of restoration actions (O'Brien et al., 2025).

The limited success of some restoration projects can be linked to the low genetic diversity of transplanted material. Projects using high-diversity stocks have been shown to be more successful, resulting in higher post-restoration population growth (speed and overall success). To improve monitoring, it is proposed to adopt demographic monitoring of natural and out-planted populations to determine changes in population growth rates or sexual recruitment rates over a long-time frame (Baums et al., 2019).

To incorporate genetic diversity in restoration plans, it is essential to select feasible and inexpensive methods for assessing and monitoring genetic diversity. DNA-based monitoring is increasingly accessible due to reductions in the costs of DNA sequencing and genotyping. However, barriers remain. Thus, genetic diversity can also be accessed by non-DNA proxies, such as effective population size (Ne), which can be inferred by census counts. Ideally, both strategies (demography and genetics) should be combined.

Understanding the process shaping and maintaining patterns of biodiversity underlies better conservation and restoration practices. Connectivity, defined as the exchange of individuals among populations (demographic connectivity), and their successful reproduction (genetic connectivity) are of critical importance in the functioning of restoration projects (see Section 6). Integrating population genetics and demographic information (demo-genetic approaches) allows the estimation of contemporary connectivity to select source material and provide estimates for the size, density, and distance among restored populations (Gazulla et al., 2021), guaranteeing that re-establishing populations are self-sustaining, demographically stable, and genetically variable, ensuring their long-term viability and adaptability to future environmental changes.

For using genetic diversity to plan and monitor the restoration of marine ecosystems, it is important to consider the following:

- What information is available on the reproduction and life-history traits for targeted species (e.g., type of reproduction, population sizes, duration and period of reproduction, brooding periods, etc.);
- What metadata (characteristics of the physical environment) are available on the possible source locations (provenance areas);
- What genetic data is available on the target species (types of measures of genetic differentiation available, such as Fitness threshold data, the amount of genetic variance that can be explained by population structure, and type of marker/loci used).

With these data, it is possible to generate species-specific models and predictions of genetic turnover and its relationship with environmental data, enabling proper planning of where to source material, distance from source, size, and density of the restored patches. An example of this functioning is Reef Adapt (www.reefadapt.org), a globally applicable web platform that incorporates genetic, biophysical, and environmental modeling into marine restoration and assisted gene flow planning (Wood et al., 2024), aiding to enhance resilience to future change and to base scientifically robust decision making.

5.1.4 State of the Physical and Biotic Environment

The environment defining physical, chemical, geological and biological conditions, their interactions and feedback mechanisms provide the fundamental conditions for the presence of habitats and therefore for species. Many of these properties interact and impact each other. For restoration to be successful, the main limiting properties have to be identified. The recovery of the physical/chemical condition of, for example, sediments in relation to factors like organic enrichment and grain size structure will provide the context for potential recovery/re-establishment of communities and species (e.g., Lim et al., 2006). The same will apply to other habitat types, e.g., in relation to occurrence of hypoxia in the bottom water layers or removal of hard substrates due to bottom affecting fishing gear.

Of particular relevance in the context of restoration is the fact that many organisms interact and shape the environment and thus alter the local physical and chemical conditions. These interactions and feedback processes can thus lead to changes in the local environment that facilitate the ability of other species to be established. There are several examples related to foundation species such as reef-building organisms (e.g., oysters) or habitat structuring organisms (e.g., seagrasses) that fundamentally change the local physical environment in ways that then alter and facilitate conditions for other organisms that otherwise would not have proper local conditions for their existence. The dominant species and their interactions are of major interest and can be evaluated through food web analyses, tracing energy flow in the ecosystem, or identifying important community interactions such as predator-prey relations.

In the following, we will present the main physical, chemical, geological and biological factors of particular relevance for the establishment (= presence) and thus reestablishment or recovery of marine species and habitats. The scene-setting properties for the reestablishment of a self-sustaining ecosystem in a specified region are:

- Physical properties: density, salinity, temperature, waves , tides, vertical lateral dynamics, shear stress at the bottom, turbidity, light penetration depth;
- Chemical properties: oxygen concentrations/vertical profile/ frequency of oxygen limitations, nutrient concentrations, heavy metals/toxins, organic content of the sediments;
- Geological properties: substrate structure, grain size;
- Biological properties: biodiversity, species distribution including the larger region biological seascape/ potential / localized home ranges, community structure (e.g. major species present and their interactions), interactions among organisms (predation, competition, and symbiosis), mobility of species.

The complexity of the interactions between these properties and the cross impacts that alterations can have is high.

5.1.5 Spatial Scales of Protection

For restoration of biogenic habitats such as seagrass, mussel beds, oyster reefs or *Sabellaria* reefs, minimum areas of, e.g., hectares or square kms per site, are needed for long-term persistent (resilient) self-sustainable habitats. For seagrass, larger-scale efforts hold a larger likelihood of success (OSPAR, 2024). Connectivity is crucial in terms of larval dispersal distances or seed transport distances, with typical distances of kilometres. Not only is a minimum area important, but also an optimal restoration density of the species (Govers et al., 2022 and references therein).

5.1.6 Identification/Delineation of Locations Suitable for Restoration of Features

The Annex II of the restoration law (Office of the European Union, 2024) described a list of biogenic habitats such as coral reefs, seagrass beds or deep-sea sponge grounds that need to be restored. For this purpose, to delineate current and past distribution of these habitats is a key aspect of any restoration effort since it allows us to quantify the proportion of each habitat in good and bad condition (and therefore to assess if they need to be restored) as well as to delineate suitable areas for these efforts. Unfortunately, this is a major challenge especially in marine ecosystems. A difference from terrestrial ecosystems, where direct methods (such as satellite images) allow mapping most of terrestrial ecosystems, sometimes even several decades in the past, mapping marine habitats with direct methods is only possible for the shallowest habitats and not in all cases. Therefore, there is an important gap in the availability of distribution maps for many of the habitats listed in the EU Restoration Law (Section 4.7), especially in certain areas of Europe. Furthermore, human pressures in the marine ecosystems have existed for years, sometimes even decades, making it difficult (and sometimes impossible) to assess how much of the original distribution of these habitats have been already lost. This is especially important for the most sensitive of these habitats, which usually are restricted to refuge areas. Failing to include such habitat loss in the assessment of its status may lead to a biased evaluation because of the lack of the resulting lack of overlap with the pressures (De la Torriente Diez et al., 2022). In deep sea marine ecosystems, most of the currently available maps of biogenic habitats are the output of models, usually species distribution models, also called ecological niche models, habitat suitability models or just distribution models (see further Section 5.3.4). These approaches can provide relevant information to compute the distribution of biogenic habitats, but they also have important limitations that need to be considered before being applied. Further, it is critical to consider connectivity network for evaluating whether modelled distributions of suitable habitat can be colonized (e.g., Wang et al., 2022; Section 6).

5.2 Empirical Methods to Measure Recovery

This section summarizes approaches to evaluate the success of restoration, and the ability to detect this success for different groupings and parameters, to address ToR B): 'Summarise available methods to monitor and assess the rate of recovery of marine habitats and species, the resources required to apply these methods, the scales of implementation and their statistical power to detect recovery on defined timescales. Identify additional evidence needs to guide effective monitoring and assessment of the effects of management measures intended to achieve restoration.'

5.2.1 Phytoplankton

5.2.1.1 Methods for monitoring

Phytoplankton can be monitored using pigment analysis via water filtration and HPLC (High-performance liquid chromatography) (Castellani and Edwards, 2017). This technique identifies the main phytoplankton groups and their biomass. Alternatively, species can be counted under the microscope. Other methods for species analysis include the use of a flow cytometer or in situ flow cytometry (e.g., CytoSense) and eDNA analysis (van Oevelen et al., 2022). For primary production, a suite of other methods is available including satellite data and in situ measurements of primary production. A ferrybox has been developed to combine sensors in one box (van Oevelen et al., 2022).

5.2.1.2 Methods to assess recovery (choice of response variable, statistical model used)

Under OSPAR, there are several indicators that assess trends related to plankton diversity, abundance and community composition. In the indicator '*Changes in Phytoplankton and Zooplankton Communities*' the focus is not on individual species, but on plankton life forms, such as holoplankton, large copepods, fish eggs, small copepods or gelatinous plankton (Holland et al., 2023). Other indicators are 'Changes in Phytoplankton Biomass and Zooplankton Abundance' (Louchart et al., 2023a) and 'Changes in plankton diversity' (Louchart et al., 2023b).

5.2.1.3 Resources required to apply the methods (with a link to power analysis and the scale of implementation)

For offshore monitoring of plankton, vessels are needed. CPR monitoring takes place from commercial vessels. For innovative monitoring, several projects have been set up, e.g., in the Netherlands, under the MONS program (https://www.noordzeeloket.nl/en/network/north-sea-consultation-0/mons-research-monitoring-programme/), innovative plankton monitoring is tested. Abundance trends for planktonic lifeforms can be evaluated over time by applying the Kendall trend test to annual mean abundance values (see references in Holland et al., 2023).

5.2.2 Zooplankton

5.2.2.1 Methods for monitoring

Zooplankton is traditionally monitored through net sampling or plankton torpedo sampling during dedicated scientific surveys. In addition, fish larvae surveys and fish eggs surveys are conducted for commercial species such as herring and mackerel. Plankton is also recorded through the Continuous Plankton Recorder on board of commercial vessels since 1931 (https://www.cprsurvey.org/), usually at high speed (up to 25 knots). Pumping is also used for larger volumes, such as the Continuous Underway Fish Eggs Sampler (CUFES). New technologies consist of optical imaging in combination with AI, such as the FlowCam (https://www.fluidimaging.com/applications/aquatic/plankton-research), the ZooScan (http://www.hydroptic.com/index.php/public/Page/product_item/ZOOSCAN) and the plankton imager (https://visionrobotics.eu/maritime-research-on-cusp-of-computer-vision-and-robotics-breakthrough/).
To determine real-time and large-scale estimates of biomass or migration patterns, acoustic methods can be used (Acoustic Doppler Current Profiler (ADCP), echosounders) (Jak et al., 2020; Holland et al., 2023).

5.2.2.2 Methods to assess recovery (choice of response variable, statistical model used)

See phytoplankton above (section 5.2.1.2)

5.2.2.3 Resources required to apply the methods (with a link to power analysis and the scale of implementation)

See phytoplankton above (section 5.2.1.3)

5.2.3 Macrophyte Populations and Habitats

Macrophytes are highly productive foundation species found in shallow coastal and estuarine environments, including macroalgae, seagrass beds, and mangroves. This report focuses specifically on seagrass meadows, as they are a frequently restored macrophyte habitat within a European context. Four native species of seagrass are found in Europe, inhabiting both intertidal and subtidal environments (Borum et al., 2004). Where monitoring methods are not applicable across habitat types, distinctions will be made accordingly.

5.2.3.1 Methods for monitoring

The most widely employed monitoring techniques for seagrass meadows include visual census methods, aerial surveys and remote sensing, and acoustic monitoring (Kirkman, 1996). In situ observations are carried out using drop-down cameras and detailed dive surveys for subtidal environments and walking surveys during low tide in intertidal areas. Still images and video surveys captured during these surveys allow for further visual analysis. Quadrat sampling, commonly used to assess seagrass coverage, may be conducted through randomly generated sampling points or along transect lines extending across the bed with quadrats typically spaced every 5-10 m (Gamble et al., 2021). Passive acoustic monitoring devices and echosounders employ sonar technology to monitor seagrass distribution and density have also been used to enhance monitoring capabilities (La Manna et al., 2024).

The choice of monitoring method depends on the spatial scale of the seagrass meadows and the available resources. Large-scale mapping efforts often rely on remote sensing which offers high spatial resolution, particularly where extensive in situ observations are not feasible. However, remote sensing must be supplemented with targeted ground surveys to validate observations and are only appropriate at certain depths and are often compounded by environmental conditions such as water turbidity and light (Ventura et al., 2022).

As with other monitoring strategies discussed in this report, comparative assessments against natural reference habitats within a suitable distance from the restoration site should be used. Many existing seagrass beds are highly degraded and may not constitute an appropriate reference with which to compare. In such cases, or where a natural reference is not available, method design should consider following a before/after/control/impact concept. In both cases information on baseline conditions prior to the start of restoration is recommended as a starting point from which to measure recovery.

5.2.3.2 Methods for Assessing Recovery

Seagrass meadows are highly susceptible to degradation, with current estimates indicating that restoration success rates are as low as 37% (van Katwijk et al., 2016). Consequently, many recovery assessment methods focus on evaluating seagrass survival through metrics such as abundance and percentage cover. More detailed vegetative structural metrics provide deeper insight into recovery status. These include shoot density, leaf morphology and leaf area index, flowering prevalence, disease assessment and biochemical parameters (Carr, 2011; Ruiz-Diaz et al., 2024) which collectively capture the overall health, growth, and reproductive potential of seagrass populations.

More complex metrics include biomass estimation which measures the organic material present in seagrass meadows. Traditionally, this is determined by collecting and drying above- and below-ground vegetation (leaves, shoots, rhizomes, and roots) (Kirkman, 1996). Alternatively, biomass estimates may be inferred from quadrat photographs by comparing restored seagrass meadows to reference sites with known biomass values (Kirkman, 1996). Genetic profiling of restored seagrass meadows can further aid in recovery assessments, as higher genetic diversity is often linked to increased resilience in restoration projects (Gamble et al., 2021). However, such analyses are not always feasible due to resource constraints and can be highly technical.

In addition to structural recovery, seagrass meadows provide critical ecosystem services, including nursery habitats for juvenile species, water filtration, and carbon sequestration. Restoration success is frequently determined by the return of these ecosystem functions. Consequently, functional metrics may also be used to assess recovery (Ventura et al., 2022). Specific methodologies for measuring these functions are not detailed here, as they are covered in other Sections, or fall beyond the scope of the report.

Statistical analysis of recovery has to date been varied, with both multivariate and univariate methods performed (van Katwijk et al., 2016). Univariate examples collate multiple seagrass restoration initiates and measure their performance through initial trial survival and long term success (van Katwijk et al., 2016).

5.2.3.3 Resources Required for Monitoring Methods

Remote sensing methodologies generally are a low-cost option which require fewer field resources but can be computationally intensive, necessitating expertise in analysis software such as GIS.

Visual census techniques, including quadrat and transect sampling, are relatively low cost but can be labour-intensive and time-consuming. Many restoration projects have incorporated citizen science initiatives to support monitoring efforts and enhance data collection capacity (Jones et al., 2018). This also has the added benefit of fostering public awareness and encouraging stewardship of marine environments.

Conclusions on the state of the health of seagrass meadows should be carried out at appropriate spatial and temporal scales to detect change. Seagrass restoration trials are often conducted on a small spatial scale, allowing for comprehensive monitoring coverage (van Katwijk et al., 2016). This enhances the statistical power of recovery assessments by increasing the likelihood of detecting changes over time. To ensure robust data analysis, an appropriate number of representative samples should be collected, ideally incorporating multiple complementary assessment methods.

5.2.4 Invertebrate Benthic Populations and Communities, and Habitats

The benthos can be broadly split into soft- and hard-bottom populations and communities, but most of the considerations below are valid for both.

5.2.4.1 Methods for monitoring

Monitoring recovery of benthos will require repeated quantification of abundance or biomass of populations and communities over a time period that matches the expected time-scale of recovery of the species involved, in the area where the restoration action is being performed (e.g., removal of a pressure or active restoration), as well as in control locations (if these exist) (e.g., Dernie et al., 2003; Z. Wang et al.; 2021). Monitoring needs to occur at the spatial scale of the restoration action, and the sampling gear needs to match the living habit and abundance of the species (for example, a rare sessile epifaunal species needs to be monitored with a trawl or video that samples a large enough area to get a reliable density estimate) (e.g., Froján et al., 2016). The frequency and duration of monitoring needs to match the expected recovery time-scale, which is likely to be less frequent and of longer duration for the more sensitive larger and long-lived species that are often used as indicators of ecosystem health (e.g., Jenkins and Uyà, 2016).

The EU Restoration Law covers a wide range of benthic habitats, from biogenic habitats (Groups 1-6, e.g., seagrass beds) to broad habitats (Group 7, e.g., Atlantic circalittoral mud) and a wide range of depths (from 0-1000 m deep, from infralittoral to bathyal habitats). These broad range of habitats are monitored using a wide range of tools, including indirect and direct methods, from scuba diving (first metres of depth) to sampling from research vessels (for circalittoral and bathyal habitats). Direct methods (such as beam trawls or sediment dredges) are more common in circalittoral and bathyal habitats in soft sediments whereas visual methods are frequent in shallow areas (using scuba diving or small ROVs) or rocky habitats (using ROVs or photogrammetry sledges). The sampling method (for both monitoring and measurement of recovery) is therefore defined according to the benthic habitat characteristics, with depth and substrate type being key aspects of this decision.

5.2.4.2 Methods to assess recovery (choice of response variable, statistical model used)

The most commonly monitored response variables for benthic invertebrate populations are numerical abundance, biomass, % cover, and a variety of biodiversity metrics (van Denderen et al., 2024). Other approaches include evaluating changes in functional composition such as life-history traits, feeding guilds, and mobility patterns to understand functional recovery. Several complex metrics that aim to be compound indicators of ecosystem health are also commonly used (e.g. Muxika et al., 2007; van Denderen et al., 2024).

Recovery is commonly evaluated using both univariate and multi-variate statistics. In univariate analyses, by fitting linear recovery trajectories, recovery is often implicitly assumed to be a constant process (e.g. Dernie et al., 2003), although a substantial fraction of studies does fit more plausible shapes to the recovery trajectory (e.g., logistic population growth, Kaiser et al., 2018). Multivariate Analyses are commonly used to evaluate how community composition is responding to changes in pressures (e.g., Van Colen et al., 2010). These analyses do not make assumptions about the shape of the recovery trajectory, but the interpretation of recovery trajectories in multidimensional space can make it difficult to assess the rate and completeness of recovery.

5.2.4.3 Resources required to apply the methods (with a link to power analysis and the scale of implementation)

Seabed habitats are very extensive, and some sedimentary habitats cover 10s of thousands of km^2 within the EEZ of a country (EMODnet, 2021). Monitoring the state, and therefore the recovery, of such large and heterogeneous areas through seabed sampling, with enough power to detect change, can be impractical due to high expense and limited resources. This is particularly true for rare species and sampling methods that only sample small areas (e.g., grabs for infauna), as well as where sample processing time can be extensive (e.g. grabs, video analysis of the whole community). Analyses have been performed to evaluate the power of monitoring programmes to detect changes, showing that the power to detect change is low for most indicators (Van Wynsberge et al., 2017), and that increasing the sampling effort during each sampling campaign had a larger effect on the time taken to achieve high power to detect changes, compared to increasing sampling frequency (Perkins et al., 2021).

5.2.5 Fish Populations and Communities, and Other Exploited Species

5.2.5.1 Methods for monitoring

Assessing marine commercial fish stocks and their recovery rates involves a combination of fishery-independent surveys and fishery-dependent data. Methods applied in the ICES area associated with fishery-independent surveys provides unbiased data on fish populations (stocks) and includes; (i) *Bottom Trawl Surveys*, which are standardized surveys using GOV trawl nets to sample demersal (bottom-dwelling) fish species. For certain shellfish species other types of trawl nets and dredges are used, such as *Nephrops* trawl nets and underwater television systems (UWTV). Dredges, pots and traps are also used to sample/ capture scallops, lobster and crab. The surveys are conducted at specific times of the year and cover predefined areas to ensure consistency, (ii) *Acoustic Surveys*, these use sonar technology to detect and estimate the abundance of pelagic (mid-water) fish species. The data collected includes fish density and distribution patterns, and is validated against samples collected using pelagic gill and seine nets (iii) *Fish Egg and Larvae Surveys*, these surveys focus on the early life stages of fish using different types of nets and traps which, notably have fine mesh sizes. These include *Bongo* nets, which are paired, cylindrical nets that are towed horizontally through the water. They are effective for collecting ichthyoplankton (fish eggs and larvae) and allow for simultaneous sampling at different depths; *Ring* nets and *CalVET* nets; which are vertical egg and larval nets designed for quantitative sampling. They are often used in coastal and offshore surveys. For coastal and estuarine surveys, seine nets and fyke nets are routinely deployed, and in these dynamic environments using a multi-metric approach is often advised to capture the range of fish species which may be present across a mosaic of habitats (Colclough et al., 2005).

5.2.5.2 Methods to assess recovery (choice of response variable, statistical model used)

Collected data, which includes information on the distribution and relative abundance/ biomass of fish, as well as other biological parameters (e.g., age, length), are used to determine a range of stock assessment metrics, e.g., (i) *spawning stock biomass* (SSB) which is used to assess the reproductive capacity of the stock, (ii) *fishing mortality* (F) which is the rate at which fish are removed from the population due to fishing and is compared to reference points to determine if the stock is overfished or not, (iii) *recruitment* (R) which is the number of young fish entering the population. It is an important indicator of future stock productivity and recoverability.

Various models are used to generate these metrics, notably; (i) *Age-Structured Models*: which use age composition data to estimate mortality rates, growth rates, and recruitment and includes Virtual Population Analysis (VPA) and Statistical Catch-at-Age (SCAA) models, (ii) *Biomass Dynamics Models*: which estimate changes in fish biomass over time based on catch and effort data. They are useful for data-limited stocks where age composition data is not available, (iii) *Length-Based Models*: which use length-frequency data to estimate growth rates, mortality rates, and recruitment. They are particularly useful for species where age determination is difficult.

5.2.5.3 Resources required to apply the methods (with a link to power analysis and the scale of implementation)

Trends in stock assessment metrics, notably stock abundance and biomass, provides key guidance when setting conservation priorities, whether indicating population decline, stability or recovery. Knowledge of the power of stock assessment surveys to detect trends in recovery is therefore essential, as the consequences of not detecting a real trend can be profound. Based on the existing survey design for North Sea stocks at least 5–10 years of monitoring data would be required to detect recovery (Maxwell and Jennings, 2005), a time scale which is commensurate with MSFD monitoring requirements to assess GES. It was also noted that the power to detect trends in abundance increase by developing composite indicators that reflects trends in abundance of several vulnerable species (Maxwell and Jennings, 2005). Another important consideration is the effect that large scale human activities and projects, such as offshore renewable energy developments, may have on the power of existing surveys to assess stocks and detect change, as a result of survey effort being spatially displaced (Lipsky et al., 2024). In the case of sampling fish nursery areas, notably coastal and estuarine habitats, estimates of abundance alone may not capture realistic estimates of fish production for the total population. Therefore, efforts should be made to sample growth, survival and movement at a habitat level which may more arcuately depict recruitment to adult populations, although this is rarely achieved in practice (Beck et al., 2001; Lefcheck et al., 2019).

5.2.6 Marine Mammals and Birds

5.2.6.1 Methods for monitoring

Unless the restored habitat is extensive, the area affected is unlikely to span the entire range of most marine mammal and bird species that are highly mobile. Nevertheless, the utilisation of those areas can play an important role in their life history, and for migratory species may serve as critical staging points for feeding. However, this does pose challenges for monitoring responses to habitat recovery since many other factors elsewhere, that may not be measured, are likely to affect population parameters such as reproductive rates, juvenile and adult survival.

Some species that are relatively sedentary and have small home ranges, at least during particular seasons (e.g., summer), can serve as indicator species. Amongst seabirds, these include great cormorant (*Phalacrocorax carbo*) and European shag (*Gulosus aristotelis*), and in higher latitudes, black guillemot (*Cepphus grylle*). These mainly feed on sedentary benthic fish. Coastal marine birds that utilise shallow water areas such as estuaries and bays for feeding include species such as brent geese (*Branta bernicla*) that feed mainly on eel-grass and marine algae, common scoter (*Melanitta nigra*) and velvet scoter (*M. fusca*), common eider (*Somateria mollissima*) and king eider (*S. spectabilis*) that feed on mussels and other bivalve molluscs. Amongst marine mammals, species characterised by relatively sedentary habits at least within certain seasons include harbour seal (*Phoca vitulina*), harbour porpoise (*Phocoena phocoena*), and coastal bottlenose dolphin (*Tursiops truncatus*) all of which take a variety of flatfish and other benthic species. Where available, kelp forests are an important foraging ground for harbour seal and the coastal ecotype of bottlenose dolphin. Monitoring all of the above can include occupancy rates, and numbers using the restored area on a regular basis at particular times of year.

5.2.6.2 Methods to assess recovery (choice of response variable, statistical model used)

Standard monitoring methods include transect surveys (line transects for cetaceans, and strip transects for seabirds) using DISTANCE sampling to calculate densities and if necessary, abundance (Buckland et al., 2001, 2012; Thomas et al., 2010) and counts of pups (for grey seals) or moulting adults (for harbour seals) by vessel or plane, supplemented by tagging (Boyd et al., 2010). Annual counts at breeding sites can be used to monitor breeding population numbers of seabirds (Anker-Nilssen et al., 2020; Burnell et al., 2023) but face the complication of confounding variables affecting reproductive success such as human disturbance on land. Photo-identification studies are an important method for obtaining population estimates for bottlenose dolphin, and can be applied to seals (using photographic capture-mark-recapture methods), and to determine individual home ranges and habitat usage (Boyd et al., 2010; Evans, 2020). For habitats used by marine birds either as wintering areas or staging points on migration, direct counts of numbers made regularly provide measures of usage. However, other factors (both natural and anthropogenic) elsewhere can affect the numbers counted within the restored habitats leading to difficulties in attributing numbers directly to a response to habitat restoration. For those marine mammal species where individual identification by photography is possible, birth rates, calf survival and age-based survival of young up to independence can be determined. Ringing and re-trapping of breeding seabirds provides similar life-history information and nest site monitoring of clutch size hatching and fledging success gives estimates of reproductive success (Gaston, 2004), bearing in mind that for marine birds and seals, population parameters may be affected by human pressures on land rather than in the areas of habitat restoration.

Usage by cetaceans of restored habitats can also be monitored by acoustics (Mikkelsen et al., 2013), for example static acoustic devices such as sound traps recording whistles and other vocalisations (Sarnocinska et al., 2016) or F-PODs (echolocation click detectors) (Ivanchikova and Tregenza, 2023). Challenges still to be fully overcome include converting acoustic detection frequencies into numbers of animals and distinguishing species from echolocation clicks and pulsed vocalisations (Cotter et al., 2019; Gill et al., 2019). A metric commonly used with click detectors is detection positive minutes (DPM) which at least provide a relative measure of activity within a specific range of the acoustic device.

5.2.6.3 Resources required to apply the methods (with a link to power analysis and the scale of implementation)

A power analysis will provide an estimate of the sample sizes and number of years of monitoring required to establish a statistically significant trend in numbers and occupancy that can be used to assess recovery (Authier et al., 2020). Modelling (using GLM, GAM, GEE and/or mixed models – Zuur et al., 2009) has a specific role to play in attempting to disentangle other factors influencing spatio-temporal changes in usage of restored habitats and its consequence at a population level for particular indicator species (Fauchald et al., 2015; Waggitt et al., 2020). Despite being k-selected species (deferred maturity, low fecundity, and high survival yielding, for the most part, extended generation lengths – Evans and Stirling, 2001; Gaston, 2004), many marine mammals and birds are highly mobile resulting in them being more likely to respond rather quickly to habitat change by comparison to more sedentary or sessile taxa.

5.2.7 Biodiversity

Biodiversity is one of the main elements of ecosystem health and habitat restoration, but the term biodiversity itself has many definitions. At an overall level, biodiversity reflects the variety of life at a place. The most common use of biodiversity is **species** or **community** diversity which is related to the species composition in a community. Other types of biodiversity that can be considered are **genetic** diversity, **functional** diversity and **habitat** or **ecosystem** diversity. In all cases, diversity refers to the number and distribution of the diversity feature of interest, but how this assessed depends on the feature and the scale at which this feature is expressed. Below we will examine which elements of these different biodiversity.

Depending on the scale and focus of restoration interventions, different biodiversity elements (defined below) can be relevant and should be considered to be assessed. In all cases, monitoring the effectiveness of restoration requires following changes over time. Ideally one should have biodiversity data before the restoration efforts and afterwards. BACI experimental designs (Underwood, 1994) (including unrestored "control" sites) would be ideal experimental designs for assessing the impact of restoration. Data monitoring designs that measure over time will provide even better assessments of the impact and temporal dynamics of restoration on biodiversity.

Before doing so, it is also important to be aware that biodiversity is also assessed at different spatial scales. Alpha diversity refers to diversity within a particular location, habitat or community. In contrast, beta diversity refers to comparing diversity between different locations and typically is expressed in terms of shared species or characteristics. Finally, gamma diversity refers to the overall diversity over a large spatial scale such as a landscape or region. Gamma diversity in fact incorporates both alpha and beta diversity.

5.2.7.1 Species or Community diversity

There are various ways to assess the species or community diversity at a particular site, but all require a good (i.e., nearly complete) assessment of the number of individuals of each species of the community. Community diversity can be measured simply by measuring species richness (the number of species) or species evenness (the relative distribution of individuals among species) or, more commonly, both elements at the same time. Many diversity indices include both elements (Table 5.2). Graphical methods plotting individuals versus species, such as rarefaction curves, can also be used to assess and compare community diversity. More complicated diversity assessments may include other information such as the biomass of individuals together with the number of individuals of different species. A few diversity indices commonly used are shown in Table 5.2, but there many more indices that may be used and may be relevant depending on the case at hand.

Table 5.2. Some typical diversity indices (see Clarke and Warwick (2001).

Index	Abbreviation	Comments	Additional comments
Species Richness	S	Number of species	Is very sensitive to sample size
Shannon	H´	Richness and evenness	Very common diversity index
Simpson		A dominance index	1-λ is thus an evenness index
k-dominance curves	k-dominance	Plots of cumulative ranked abundance (number of individuals) versus species ranks	The shape of the curve informs about community diversity and distribution of individuals among species.
Abundance/Biomass comparisons	ABC curves	Plots of dominance of species biomass versus species rank (by number)	

5.2.7.2 Functional diversity

In functional diversity, the focus is not on species, but rather the ecological function of community members. This is of course closely related to species and their ecological niches and functions, but it does acknowledge that different species may have similar ecological functions. Assessing functional diversity is typically done by assigning functional traits to different species. This assignment or translation to functional traits is the key and often limiting step as it requires knowledge of the ecological functionality of all species that are present in a community. This has been successfully done in some case for plant, fish or benthic communities, but information about the ecological functionality of many species is still lacking. Once defined, the diversity of functional traits is then assessed using similar metrics as species diversity (Section 5.2.7.1).

Another way to approach functional diversity is to assess ecological processes themselves. This is a step further from the community level of biodiversity and moves towards the ecosystem level and its functioning. It entails quantifying ecosystem processes, but typically most ecological processes are present in most ecosystems, so this is more about quantifying the size or rates of such processes. This requires process measurements. This may in fact be relevant in some restoration situations, but it is a deviation from the typical biodiversity assessments.

5.2.7.3 Genetic diversity

Genetic diversity focuses on diversity at the gene, allele or DNA level. It thus is at a lower biological scale than individuals, but it also is affected biodiversity at higher levels. One approach to assess genetic diversity is to measure allele frequency. The method for assessing alleles can differ but is typically based on targeted DNA sequencing with designed genetic probes to select genes of choice then measuring the DNA base differences to identify the presence of different alleles for the chosen genes. Once the number of alleles is determined, then allele diversity (with an index) or allele richness is used to describe the genetic diversity. Note, the number of alleles that can be assessed is related to the number of genetic probes that are used (and on which species). This is not likely a feasible method for monitoring the effectiveness of restoration in most cases, but if a particular species is of interest or topics like genetic connectivity are relevant, then analyses of genetic diversity and relatedness can be useful for assessing the success of restoration efforts.

When comparing genetic diversity among different species, it can be an advantage to focus on common, conservative, genetic content. Ultra-conserved elements (UCE's) are highly conserved genomic regions that are shared by many, even evolutionary divergent taxa (Faircloth et al., 2012). Analyzing the variability in UCE's can thus be a way to assess and compare the genetic diversity of a community with different species (as opposed to analyzing the genetic diversity within a single species). This method has been used to characterize a wide variety of ecological communities, including marine (Erickson et al., 2021; Petersen et al., 2022).

5.2.7.4 Habitat diversity

Habitat diversity refers to measuring the number and distribution of different habitats within an area or region. This is often accomplished by categorizing and mapping area of different, visible habitat types. As such it is typically macroscopic features that form the basis for assessing habitat diversity. GIS and remote sensing methods are useful for assessing habitat diversity. Focusing on biodiversity at this scale is likely more relevant for restoration efforts that occur at larger scales such as seascapes or for efforts that are affected by large-scale issues (e.g., connectivity; Section 6).

5.2.8 Marine Secondary Production

Marine secondary production refers to the biomass generated by heterotrophic organisms, including zooplankton, benthic invertebrates, and nekton. It plays a crucial role in marine food webs and ecosystem functioning (Kaiser et al., 2020; Dolbeth et al., 2012). The monitoring of marine secondary production are essential for evaluating the success of restoration of ecosystems after disturbances and for assessing the effectiveness of conservation measures (Dolbeth et al., 2012). It has been argued that secondary production is an underused metric to assess restoration initiatives, and in marine systems has mostly been used in estuaries and not in offshore areas (Layman and Rypel, 2020).

5.2.8.1 Methods for monitoring

Monitoring the recovery of marine secondary production requires repeated quantification of biomass, abundance and body size for the whole community evaluated (e.g. benthic invertebrate communities), over a time period that aligns with the expected recovery time of the target species and trophic levels. Measuring secondary production can be very resource intensive because it requires repeated samples to get a single production estimate if a cohort analysis method is used (e.g., Reiss et al., 2009a). Allometric relationships are less precise but likely to be much more resource effective (Kaiser et al., 2020). This monitoring should be conducted both at the restoration site (e.g., where a pressure is removed or an active restoration effort is undertaken) and at control sites for comparison.

Monitoring must occur at a spatial scale appropriate for the restoration action. Sampling methods should be tailored to the specific secondary producers being assessed (see other sections in Section 5.2).

5.2.8.2 Methods to assess recovery (choice of response variable, statistical model used)

The most used response variables for assessing marine secondary production is biomass production per unit area or volume per year (Kaiser et al., 2020). Recovery assessments should employ univariate statistical approaches, and although linear recovery trajectories are often assumed, more complex models such as logistic growth curves or Gompertz models are more appropriate as recovery is highly likely to show density-dependent recovery patterns (Gomez, 2015).

5.2.8.3 Resources required to apply the methods (with a link to power analysis and the scale of implementation)

Monitoring marine secondary production at ecologically relevant spatial scales presents significant logistical challenges. Many marine habitats cover vast areas, and obtaining sufficient data to detect changes in secondary production is expensive and resource-intensive. This is especially true for mobile species requiring large-scale surveys (e.g., trawl surveys, acoustic monitoring) and for labour-intensive sample processing techniques (e.g., microscopic plankton analysis).

Power analyses to detect significant changes in secondary production of monitoring programs indicators were not found in the literature, but can assumed to be limited due to high natural variability and the need for extensive sampling. Increasing the spatial coverage and sampling effort within each survey period tends to be more effective for improving detection power than simply increasing sampling frequency. Advancements in automated data collection, such as machine learning algorithms for image processing, may help reduce costs and improve monitoring efficiency in the future.

5.2.9 Food Webs

5.2.9.1 Methods to monitor food web recovery

Monitoring the recovery of food webs requires repeated quantification of key trophic interactions, species abundances, biomass, and energy flows over a time period that aligns with the expected recovery trajectory of the ecosystem. Ideally, this monitoring should be conducted both within the restoration area (e.g., where a pressure has been removed) and in control locations (if available) to distinguish natural variability from recovery effects.

There are a wide range of indicators available that are currently used to assess the state of food webs, targeting energy flow, food web structure and resilience (Rombouts et al., 2013; Tam et al., 2017). These same indicators can track recovery. Tam et al. (2017) reviewed over 60 potential food web indicators, identifying those suitable for operational use and others with promise for future policy and management applications.

Food-web indicators, and associated methodologies, can be grouped into four broad categories:

- **Trophic structure indicators**: Species richness across trophic levels, the large fish indicator, predator-prey ratios, and trophic position shifts (Shannon et al., 2014);
- **Size-spectra:** biomass distributions across trophic levels, i.e. Sheldon spectra (Daan et al., 2005; Jennings et al., 2002; Kenitz et al., 2019);
- **Dietary tracers**: Stable isotopes and fatty acids to examine changes in diet composition, food web hypervolumes, energy pathways, and trophic niche width (Cresson et al., 2020; James et al., 2020b);
- **Network-based approaches**: Assessment through diet analysis of, for example, trophic vulnerability, connectance, generality and functional redundancy (Pecuchet et al., 2020; Thompson et al., 2012).

The assessments of the state of food webs rely on various statistical methods, both univariate models that can track changes in single indicators, as well as multivariate analyses, which assess shifts in community composition and trophic structure (Kortsch et al., 2015).

5.2.9.2 Resources required to apply the methods (with a link to power analysis and the scale of implementation)

Food webs operate at large spatial scales, often extending across entire ecosystems. Monitoring changes in trophic interactions requires data collection across broad areas, making comprehensive sampling logistically challenging and resource intensive. For example, pelagic food webs span open ocean systems, requiring large-scale acoustic surveys, while benthic-pelagic coupling may necessitate seabed sampling of both biomass and rates, as well as, sampling of pelagic habitats (Griffiths et al., 2017). The complexity of food web recovery means that restoration effects may take years to become evident, necessitating long-term data series to detect trends. Recovery is often constrained by the slowest-recovering group in the ecosystem, which is frequently top predators (Fortuna et al., 2024).

There is currently no comprehensive assessment of power analysis in relation to food web indicators and recovery.

5.2.10 Supportive Restoration Parameters

'Supportive' parameters are not aimed at measuring the success of restoration, but are intended to assist explaining success or failure of the applied restoration measures. They can help to improve subsequent adaptation and application of measures (Baggett et al., 2015; Zu Ermgassen et al., 2021). The most relevant parameters to consider in this context are described in this section. Most of these are of a physical/chemical nature because the local physics and chemistry may inhibit habitat development, and because there may be feedbacks between habitat development and these parameters.

To illustrate this, we use the example of seagrass: if there are anoxic conditions or strong turbulence at seafloor level, or if sediment composition is unsuitable, there is a low chance of successful local restoration of a seagrass meadow. Hence, characterizing such factors beforehand is important. On the other hand, if seagrass is established above a critical density over a sufficiently large area, it will change the local physical, chemical and probably also biological characteristics, influencing its sustainability and further development and therefore the success rate of the restoration.

The following list gives the parameters and indicates to some extend the preferred frequency and location to be surveyed in brackets where applicable:

- **Physics:** density structure (continuous, close to the substrate of the restored region), Temperature (for growth), Viruses & Bacteria (intermittent , close and above the restored area), Salinity, Shear stress (continuous ADCP, close to the substrate of the restored region), Currents (continuous ADCP, close to the substrate of the restored region), Sediment composition, Sedimentation rate, Turbidity.
- **Chemistry:** Oxygen (continuous, close to the substrate of the restored region) (Baggett et al., 2015), pollutants such as heavy metals (intermittent), Nutrients (intermittent, close and above the restored area.
- **Biology:** Pathogens, Invasive, non-native species.

5.3 Predictive Modelling of Recovery Times

Predictive modelling is a highly useful tool to consider suitable habitat for restoration and to project possible outcomes of passive and active restoration into the future. Predictive modelling is currently the only available practical tool for assessing recovery times at the scale of entire habitats and ecosystems. However, there is no 'one-size-fits-all' modelling approach and data constraints and purpose should be considered prior to application. This section defines modelling methods that are used for predictive modelling of recovery times. We classify these methods within four broad modelling categories:

- Population dynamic models
- Food-web, ecosystem and multispecies models
- Meta-population models
- Habitat suitability models

In each section, we describe the methodology with examples of how the approach is currently used. These examples can include current modelling methods that are used within the ICES network to estimate recovery. We then summarize the data requirements, and we explain how the method deals with uncertainty in recovery timeframe predictions.

5.3.1 Population Dynamic Models

Population dynamic models are mathematical models used to describe and predict changes in the size, structure, and composition of populations over time. These models help understand how populations grow, decline, or fluctuate, and how various factors (like birth rates, death rates, migration, and environmental conditions) affect population changes.

5.3.1.1 Logistic growth models

A logistic growth model is a mathematical model used to describe population growth that slows as it approaches a carrying capacity. Logistic growth accounts for environmental limitations, such as resource availability, competition, and habitat constraints. The equation of the logistic growth model is:

$$P(t) = \frac{K}{1 + \left(\frac{K - P_0}{P_0}\right) e^{-rt}}$$

Where P(t) = population at time t, P_0 = initial population size, K = carrying capacity (maximum sustainable population), r = intrinsic growth rate and e = Euler's number.

Example of benthic community recovery times

Logistic growth models can help estimating how long a species will take to reach a stable population size after a decline. These models, along with closely related approaches that build on the logistic growth model, such as the Ricker model and surplus production models, are widely used to assess recovery of marine fish stocks after overfishing (e.g., Britten et al., 2017).

Box 1 presents an example of the use of the logistic growth model to estimate seabed recovery times after impacts of towed bottom-fishing gears using the ICES working group FBIT approach (ICES, 2025a).

Box 1. Estimating recovery times for benthic communities impacted by mobile bottom fishing activities using the seafloor assessment method of ICES WGFBIT

WGFBIT uses a population dynamic model to assess the state of soft-bottom seafloor habitats from towed bottom-fishing gears. The method is based on an equation for relative benthic status (RBS, defined as the biomass B relative to the carrying capacity K), derived by solving the logistic population growth equation for the equilibrium state (Pitcher et al., 2017). RBS = B/K = 1- F d/r. Here, trawling effort (F = Swept Area Ratio) is defined as the total area swept by trawl gear within a given area of seabed in one year divided by that area of seabed (units y^{-1}). Depletion d is the fraction mortality per trawl pass estimated from experimental trawling studies, and r is the intrinsic rate of population increase. The impact of trawling on benthic biota depends on both d and r, and sensitivity to trawling depends on the ratio of d over r, and is therefore proportional to the reciprocal of the recovery rate r. The parameter estimates for d and r and their uncertainties were based on a collation from published experimental and comparative studies of the effects of bottom trawling on seabed habitat and biota following a systematic review protocol (Hughes et al., 2014; Hiddink et al., 2017, 2019), thereby avoiding selection bias.

WGFBIT estimates RBS for both total community biomass and the biomass of the most sensitive organisms. The approach can be used to estimate the time required for biomass recovery after trawling has ceased (Figure 5.5). This recovery time varies based on the initial impact and the rate at which the benthic fauna recovers. Parameter uncertainty can be estimated for each recovery trajectory (not shown).

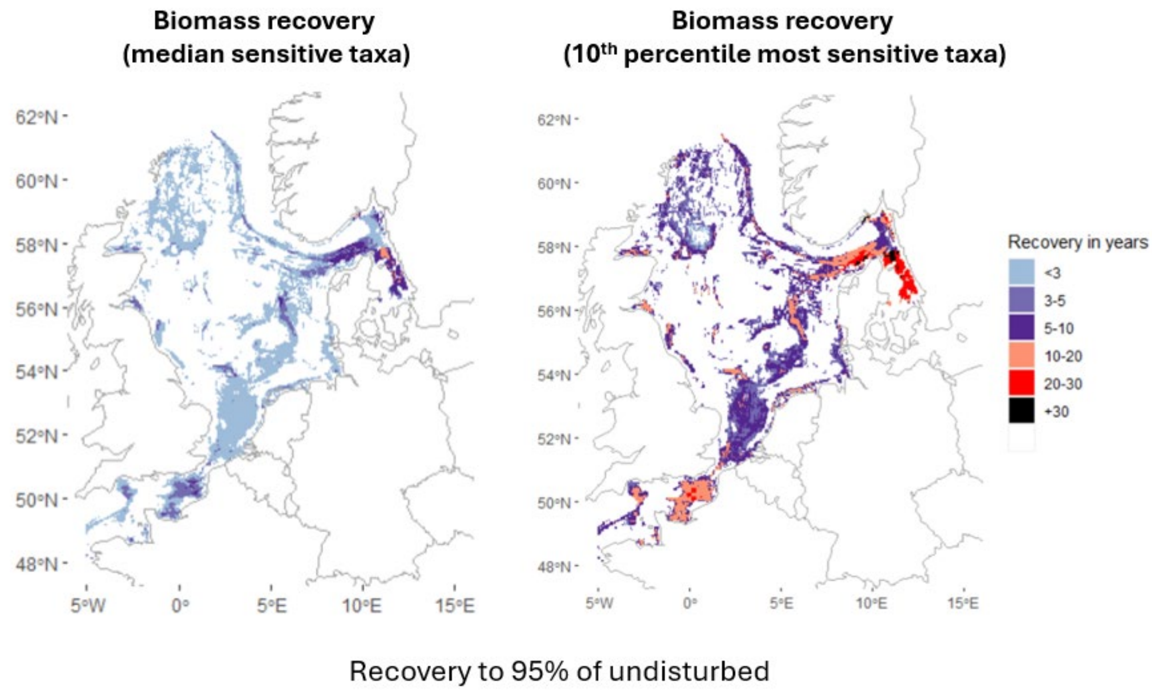


Figure 5.5. Biomass recovery of benthic fauna with a median sensitivity to fishing (left) and a high sensitivity to fishing (right). Recovery time is estimated up to 95% of carrying capacity.

Summary of data requirements

To effectively apply the logistic growth model in predicting species or population recovery, three data inputs are required:

- The population at the beginning of the recovery period, which is typically estimated through field surveys, historical data or predictive modelling;
- The maximum sustainable population size *K* the environment can support, which is determined by factors such as food availability, habitat area, and predator-prey relationships. In many marine applications (e.g. fish populations in relation to fisheries), the carrying capacity is a model-based estimate as no data exist of the population in unexploited state;
- The intrinsic rate of population increase *r* (birth rate minus death rate), which is typically derived from life-history traits such as individual growth, reproductive output, age at maturity, and survival rates. It can also be predicted using recovery trajectories of the same species in other regions.

Uncertainty in recovery timeframe predictions

The estimation of both the intrinsic rate of population increase as well as the carrying capacity are often highly uncertain as they depend on many biotic and abiotic factors including the dynamics of prey, competitors and predators in the community. This makes these parameters non-stationary. In addition, uncertainty in predicting recovery timeframes arises from data limitations (e.g., difficult parameters to sample) and model assumptions (i.e., logistic shape). To address such uncertainty, studies typically include uncertainty estimates of input parameters and the re-sampling of these parameters. Such an approach will generate probability distributions of recovery times, e.g., population 'X' will recover to 95% of carrying capacity in 30–50 years. Alternatively, models can be adapted to incorporate stochasticity or account for environmental variability, i.e., where the rate of population increase (as well as the carrying capacity) varies with environmental conditions.

5.3.1.2 Age-based and stage-structured models

Age-based and stage-based models are two approaches used in fisheries science and ecology to understand animal populations and their dynamics. Both models help manage populations, assess environmental impacts and ecosystem functions, and guide conservation efforts, but they differ in their focus and application.

Age-based models track populations based on their age, i.e., age-0 and age-1 etc. Age may be determined through otolith (ear bone) analysis or other growth markers. Age-based models assume that individuals go through predictable growth patterns and mortality rates as they age. Assumptions are made that individuals of the same age have similar survival and reproductive rates. Age-based models have been used extensively in fisheries assessments for commercial species and various age-based models exist with extensive reviews available elsewhere (Okamura et al., 2018; Batts et al., 2022).

Stage-based models classify populations into distinct life stages, such as egg, larval, juvenile, and adult, rather than specific ages. Stage-based models are useful when transitions between stages depend on environmental conditions rather than strict age progression and growth rates vary dependent on environmental factors. Again, often used in fisheries stock assessment model and are notably important for species with high early-life mortality. Stock-recruitment relationships

(SRRs) are key components of stage-based population models in some applications (Champagnat et al., 2024).

Many fisheries and ecological studies use a combination of both approaches for more comprehensive population assessments.

Example of fish habitat restoration

Champagnat et al. (2024) examined the impact of nursery habitat degradation and restoration on the productivity and population dynamics of marine fish using an age- and stage-structured model. Inshore ecosystems serve as critical fish habitats, supporting the abundance, growth, and survival of juvenile stages for numerous commercially and ecologically significant species (Beck et al., 2001). Understanding how habitat restoration influences population productivity is therefore essential for effective fisheries management. The study incorporated a steepness-based stock-recruitment relationship (SRR) within the model and parameterized habitat degradation and restoration through modifications in habitat quality and surface area. Rather than focusing on interannual variability, the model aimed to capture mid- to long-term population trends and was applied to three commercially exploited marine fish species with contrasting life-history strategies. The authors further integrated a broad range of fishing mortality rates to explore how habitat change interacts with fishing pressure.

The model predicted that alterations in nursery habitat area and quality had a direct, scalable effect on population size, biomass, and fisheries yield. Species with lower resilience to fishing were particularly sensitive to habitat degradation, highlighting the potential for compounding effects between environmental stressors and harvest pressure. While the model required substantial parameterization—some of which was selected arbitrarily—it was suggested that the framework could be applied to a wide range of exploited marine populations. However, key limitations remain. The model simplified habitat representation, assuming uniform mortality across the entire nursery area, whereas real-world habitats are highly heterogeneous. Expanding the framework to incorporate habitat mosaics with varying quality would improve ecological realism. Attempts were made by the authors to address uncertainty in parameter estimates, the authors integrated Monte Carlo simulations, providing a probabilistic approach to model robustness and sensitivity.

Summary of data requirements

To effectively apply the age- and stage- based model there are various data requirements which can be found through literature review or collecting data for parameterization. A key feature of these models is their reliance on extensive life-history trait data:

- Demographic data: age structure, stage distributions and sex-ratios;
- Growth parameters: length and weight at age which is often realized through the von Bertalanffy growth function parameters;
- Mortality rates: natural (M) and fishing mortality (F) which often need to be expressed at each age/stage in the model;
- Recruitment: Stock recruitment relationships, larval survival rates;
- Fecundity & reproduction: age and size at maturity, spawning frequency, egg production per female;
- Genetic and connectivity data: population structure, dispersal rates;
- Habitat and environmental data: carrying capacity (k), habitat availability and quality.

Uncertainty

The application of age- and stage-based models has traditionally been restricted to commercially and recreationally important species with well-documented life-history data. In contrast, many non-charismatic or less economically valuable species lack the necessary biological information for effective population assessments (Fujiwara, 2025).

The selection of an appropriate assessment model is largely contingent on data availability, with significant variability in model performance depending on underlying assumptions. A common limitation is the treatment of natural mortality as a fixed parameter for each age or stage class, often disregarding temporal variation or key biological factors such as size. Furthermore, the ability of these models to capture variability in population dynamics is constrained by their sensitivity to parameter estimates and the lack of temporal resolution in mortality rates.

Beyond data limitations, many existing models also assume static environmental conditions, failing to account for climate-induced shifts in habitat quality and population responses. Moving forward, a more integrated approach that incorporates environmental variability and dynamic life-history parameters is necessary to improve predictive accuracy and broaden model applicability.

5.3.1.3 Agent-based Modelling

Agent-based models (ABMs) use an architecture that simulates the actions and interactions of autonomous agents (e.g. individual organisms) within a system with a view to evaluating the system (e.g., population) as a whole. ABMs are sometimes referred to as Individual-based Models (IBMs), they also share in common their individual modelling basis with Cellular Automata models (CAs). However, in CAs the modelled entities are cells that remain static while spatial and other processes move across or through them. In ABMs and IBMs, the agents can move in space, interact with each other directly and their environment, and also interact with other agent types. These models can quickly become computationally very demanding, especially if large numbers of agents are modelled.

Example: recolonization of deep-sea sea pens

An example of the development and application of an ABM to study the recolonization of deep-sea sea pens and to estimate the potential historic reference conditions of sea pen populations before extensive deep sea fishing activities began (NAFO, 2018). The agents in this model represent collectives of sea pens where at each time-step the agents follow specific rules that simulate life-history processes. The agents operate within a matrix where each cell has properties that affect the behavioural responses of the agents. The processes/behaviours affecting and effected by the agents have probabilistic components which randomize the dynamics of the system.

This model was developed and implemented using Agent Analyst within ArcGIS Pro. Agent Analyst provides a software framework and tools to describe the agents, implement the processes that allow the agents to interact, and the scheduling of these processes.

The key results and conclusions of this study, serve to highlight the utility and value of using ABMs, however, they require considerable empirical data (especially with respect to the environmental drivers of biological response), along with having a good understanding of the agent's behavior in response to relevant pred-prey (food-web) interactions and habitat conditions (see Table 5.3). For example, the study was able to conclude that:

1. Following a broad-scale single perturbation event, which removed 99% of the sea pen abundance from an extensive area of sea pen habitat off continental-shelf off Newfoundland and Nova Scotia, revealed estimated partial recoveries of 50% and 80% of pre-perturbation levels in 24 and 40 years respectively (Figure 5.6);
2. Self-recruitment within an area is an important source of local growth, but overall growth also depends on connectivity between areas. Recovery times after a significant single perturbation (e.g. bottom trawling impacts) is in the order of decades (20+ years). In the context of the FAO Guidelines (FAO, 2009), these impacts on sea pens go beyond temporary impacts;
3. Refuges provide a buffer to perturbation and effectively accelerate recovery. Size and placement of refuges is key to their effectiveness. Refuge placement has to consider connectivity to be effective;
4. Broad scale recurrent perturbations of somewhat moderate level (50% removal every 4 years) can drive the sea pen status to very low levels (e.g. 20% of pre-impact), likely affecting the ecological functions provided by sea pen habitats;
5. Sea pens cannot tolerate high intensity broad scale recurrent perturbations, however, refugia can buffer high impacts, but local extinctions would be expected in medium-low suitability areas.

a) b)

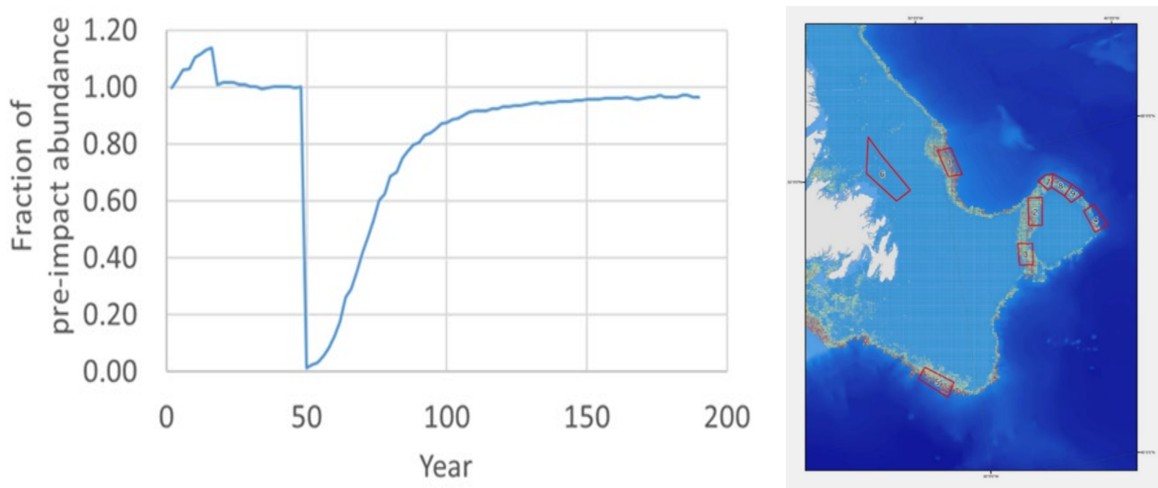


Figure 5.6. (a) Recovery trajectory of the sea pen abundance after a single perturbation removing 99% of sea pens in the impacted areas (see NAFO, 2018; for details). (b) ABM spatial domain showing simulated refugia to assess connectivity scenarios (see NAFO, 2018; for details).

Data requirements

Table 5.3. Summary description on how life-history stages/process in the sea pen ABM were modelled and parameterized.

Model Parameter/Process	Details
Number of eggs produced	Uniform distribution between 600 and 6300 per adult female (Baillon et al., 2015). Sex ratio assumed 1:1.
Number of eggs fertilized	Fertilization rate: Beta distribution, mean=0.15, sd=0.17 (Coma and Lasker, 1997). Fertilized eggs: Binomial distribution using the number of eggs in the cell and the probability of fertilization drawn from the above Beta distribution.
Larval movement and mortality	Larval life span: 15 days where the larvae either settle or move/die. Larvae can only move one cell per day. Spawning is assumed to be a Spring-Summer process. The season/period for these layers is April-August, 2000-2015 derived from Glorys 4 extracted from DFO's Ocean Navigator.
Larval movement: Direction	Heading is defined as 8 bearing quadrants (N, NE, E, SE, S, SW, W, NW). Direction of movement is randomly drawn from a normal distribution centered on the dominant bearing. This allows for counter-current movement.
Larval movement: Amount	Number of larvae to move. Binomial distribution using the number of larvae in cell and the probability of moving. Probability of moving represents the fraction of the larvae to be moved is based on the bottom speed in the cell. Logistic form with 50% probability of moving when speed in cell is equal to velocity required to travel to a neighboring cell.
Larval mortality	The number of larvae in the water column that dies each day follows a Binomial distribution assuming a mortality rate of (0.90). Sensitivity runs made with daily mortalities of 0.75-0.95.
Larval settlement	Beta distribution with mean extracted from the settlement probability layer (see Settlement Probability Section in this Report) at the cell center and the sd of the entire layer (sd=0.065). The number settled follows a binomial distribution using the amount of larvae in the cell and the probability of settlement derived from the above Beta distribution.
Post settlement larval mortality	The amount of larvae that survives settlement to become Age 0s. Binomial distribution using the number of settled larvae in cell and the probability of surviving settlement (1-post-settlement mortality). Base post-settlement mortality is 90%, but asymptotically approaches 100% when density in the cell increases at approximately 20-30k settled individuals. This represents a sea pen patch (or patches) within the cell.
Juvenile and adult sea pens	The amount of individuals that survive to become one year older follows a binomial distribution using the number of individuals at age and a survival probability of 0.90. Maximum lifespan is 20 years. Age at maturity is 4 years old.

5.3.1.4 Population Viability Analysis

Population Viability Analysis (PVA) is the use of a quantitative method to assess the likelihood of a species' survival over a given time frame under various environmental and demographic conditions. It incorporates factors such as birth and death rates, genetic variability, habitat quality, and external threats to predict extinction risk. PVA is widely used in conservation biology to guide management decisions, evaluate the impact of human activities, and develop recovery plans for endangered species.

5.3.2 Food-web, Ecosystem and Multispecies Models

Food-web, ecosystem, and multi-species models are essential tools in ecological research to understand complex interactions among organisms and their environments. Food-web models illustrate predator-prey relationships and energy flow within ecosystems, highlighting species dependencies. Ecosystem models take a broader approach, incorporating physical, chemical, and biological processes to analyse how ecosystems function and respond to changes. Multispecies models fall within these approaches, typically focusing on specific groups of interacting species, such as fish populations, to assess competition, predation, and other ecological dynamics.

5.3.2.1 Trophic models and end-to-end approaches

There is a vast body of literature on the use of trophic models and end-to-end approaches to assess ecosystem status and ecosystem functions, such as potential fisheries production and carbon export. For instance, Piroddi et al. (2015) reviewed 44 predictive modelling approaches, with over 30 falling within the trophic and end-to-end categories, evaluating their ability to provide information on indicators outlined in the Marine Strategy Framework Directive (MSFD). Their findings suggest that, collectively, these models can inform most MSFD criteria and indicators. Additionally, they observed that biodiversity and food-web descriptors were better represented than those related to non-indigenous species and seafloor integrity. The same type of approaches can be used to estimate recovery times. Here we describe two modelling approaches that have been used in European Waters to assess recovery times.

Example: StrathE2E2 and recovery in the North Sea

StrathE2E2 model is an end-to-end food web model of intermediate complexity. The model takes a mechanistic approach and examines food web responses to a variety of forcings (Heath et al., 2021). StrathE2E2 was used to examine how the biomasses of 18 functional units based on behavioural mechanisms of food acquisition rather than taxonomic groups within the North Sea are predicted to respond to 3000 scenarios of warming and changes in the intensity of fishing by three different fleet groupings (Thorpe et al., 2023). The study found that timescales of recovery following cessation of fishing depend upon both the pattern and intensity of exploitation. While recovery is fastest after light fishing pressure, it can take over 50 years following high levels of fishing and for slow-response functional groups. Interestingly, seals were predicted to recover relatively quickly despite their long lifespan and high trophic position, whereas birds and cetaceans exhibited much slower recovery rates. The longest recovery timescales were observed in carnivorous zooplankton, pelagic fish and larvae, and demersal fish and larvae, suggesting that recovery does not simply correlate with trophic level.

Example: Ecopath/ Ecosim / Ecospace

Ecopath with Ecosim (EwE) is a modelling complex that has been used to create mass balanced models of marine and aquatic ecosystems since the 1980s. Because EwE models describe the trophic flows and interactions in a system, they are useful for describing the potential effects of disturbances that change the linkages in food-webs and they have been widely used (ecopath.org) to investigate and predict the dynamics of ecosystems in response to different perturbations and management scenarios. The model-suite comprises 3 core parts; (i) Ecopath: this provides a static, mass-balanced snapshot of an ecosystem at a specific point in time. It essentially describes a food-web structure and its trophic interactions through quantifying biomass and energy flows between different species and trophic levels, (ii) Ecosim: utilises the Ecopath model to run time-dynamic simulations of ecosystem state under different perturbation/ management scenarios, e.g. to investigate how varying fishing pressures or environmental conditions impact ecosystem state over time, (iii) Ecospace: is a component of the EwE package that adds a spatial dimension to the models. It allows for the simulation of both spatial and temporal dynamics within ecosystems, making it particularly useful for exploring the impact and placement of marine protected areas, or other types of spatial management measures. Ecospace can model the movement and distribution of species across different habitats and predict the effects of spatial management measures, including investigations to assess rates of recovery of selected ecosystem components as defined by the Ecopath model.

The North Sea EwE model is one of the most comprehensive mass-balance models developed. The model structure consists of 68 functional groups including mammals (3), bird (1), fish (45), invertebrate (13), microbial (2), autotrophic (1), discards (1) and detritus groups (2). The commercially important target fish species are divided into juvenile and adult groups (e.g. cod, whiting, haddock, saithe, herring). Numerous fish species, which are also commercially and/or functionally important, are represented as single species or family groups (e.g., plaice, hake, dab, gurnards). The model is parameterised with estimates of biomass, production and consumption rates and diet composition compiled from survey data, stock assessments and literature sources and also contains information about landings and discards of various fishing gears grouped in 12 categories defined by the Data Collection Regulations (DCF) for example, demersal trawls, pelagic trawls, drift nets, etc. In-depth descriptions of the functional groups, their component species, data sources and analyses used in constructing the model are further presented in Mackinson and Daskalov (2007).

Summary of data requirements

Trophic models require extensive and diverse datasets to accurately represent ecosystem dynamics, integrating physical, biological, and human-driven processes. At the foundation, environmental data such as ocean temperature, salinity, currents, and nutrient concentrations shape the physical structure of the system, influencing primary production and energy flow through the food web. Biological data further refine the model by incorporating species biomass, abundance, and life-history traits, ensuring that trophic interactions, predator-prey relationships, and energy transfer dynamics are accurately captured.

Uncertainty

Model uncertainty arises from various sources, including incomplete or imperfect data, simplified assumptions, and the complexity of ecological interactions. To address this uncertainty, common techniques such as sensitivity analysis are used to assess how changes in input parameters impact model outputs. In addition, many ecosystem models undergo rigorous calibration and validation procedures to improve their accuracy, often using empirical observations (e.g. biomass or catch data of fish populations). However, despite these efforts, uncertainty remains a key aspect of modeling complex ecological systems. Modelling of recovery times is especially difficult as model parameters have been calibrated to current conditions and may be different in the future due to changes in human activities, predator and prey abundances as well as climatic conditions.

5.3.3 Meta-population Models

Meta-population models describe species populations as a network of interconnected subpopulations, where local extinctions and recolonizations occur due to habitat fragmentation, dispersal limitations, and environmental variability. These models are particularly useful for assessing species persistence in patchy landscapes and predicting recovery dynamics following disturbances such as fishing or habitat loss. Recovery in a meta-population framework depends on factors such as connectivity between subpopulations, dispersal rates, and habitat quality. Well-connected subpopulations with high dispersal can facilitate faster recolonization, while isolated populations may struggle to recover. In fisheries and conservation management, meta-population models help identify critical habitats that may enhance resilience, ensuring long-term population viability (Crowder and Figueira, 2006).

5.3.4 Habitat Suitability Models

Habitat suitability models, ecological niche models, predictive habitat models, species distribution models and distribution models are terms (despite small meaning differences) for models that predict the spatial distribution of a response variable (usually species presence) based on a set of explanatory variables in a GIS format (see Figure 5.7 and Section 5.1.6). Despite often being used interchangeably, the different names of these models describe slightly different concepts depending on what they are modelling (Melo-Merino et al., 2020; Peterson and Soberón, 2012). Most of them predict of the realized niche (simplifying, the current distribution of the species) whereas some of them also allow the prediction of the potential or fundamental niche of the species (areas which are suitable for the species regardless of whether the species is currently present there or not). Although most of the examples available have modelled the present-day distribution of species and habitats, these models also can be used to model future (e.g., under different climate change scenarios) (e.g., Beazley et al., 2018; Wang et al., 2022). The use of these models to predict past distribution allows for reference conditions to be hypothesized, as well as to delineate the most suitable areas for restoration (see Section 6). These characteristics make habitat suitability models powerful tools in the framework of restoration since they allow the current distribution of the target habitat to be mapped (which is a necessary first step in assessing the status of the current distribution) but also the potential distribution, areas that are physically suitable for the habitat but are currently not occupied, e.g., due to presence of anthropogenic pressures. Therefore, habitat suitability models can be used in combination with pressure distribution and/or past presence records to predict areas of habitat loss, allowing to map suitable areas for restoration.

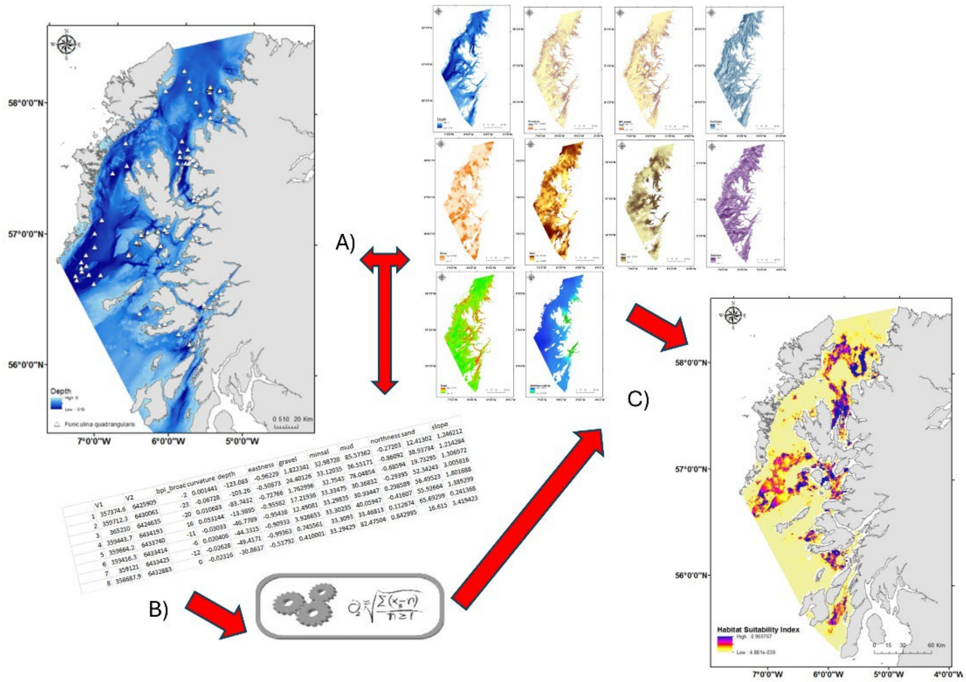


Figure 5.7. Scheme of a habitat suitability model and the different steps needed to produce a map of predicted distribution. A) Geolocated sample records are used to extract the value of the explanatory variables (in a GIS format) using their coordinates. B) The output of this extraction is a data frame that allow to fit different statistical models (e.g. GAMs, Random Forest, etc) to correlate the response variable with the explanatory variables. C) The model is applied back to the GIS layers to produce a map of predicted distribution of the response variable (usually probably of presence of one species but can also be abundance or a community/biogenic habitat or an index). Source J. González-Irusta.

Examples for evaluating the state of biogenic habitats

In the marine ecosystems habitat loss of biogenic habitats has been calculated using three different approaches; i) by using biological remains of the species as a proxy to past presences (e.g., Bergström et al., 2022), ii) to model the effect of the pressure that produce the change and then model alternative scenarios with no pressure (González-Irusta et al., 2018; Murillo et al. 2020a; Downie et al., 2021b), and iii) by combining the two previous approaches (González-Irusta et al., 2022). These approaches can provide relevant information to compute habitat loss, but they also have important limitations that need to be considered before being applied. The use of biological remains of the species or of historical records are limited by the availability of such data, which usually is scarce and incomplete. On the other hand, caution is necessary before modelling the distribution of species affected by human pressures, since a high level of impact may produce highly truncated niches (e.g., Downie et al., 2021a; Stirling et al., 2016) which cannot be easily reversed by the models. This can be reduced by concatenating models performed within different oceanographic provinces (e.g., Knudby et al., 2013; Beazley et al., 2018).

6 Methods to Quantify and Assess Habitat Connectivity with Implications for Restoration

This section corresponds to WKREST ToR c) Review and report on available methods to quantify habitat connectivity, and to monitor and assess changes in connectivity, with a focus on benthic species and habitats of the continental shelves and deep-sea. Report on the implications of habitat connectivity for recovery rates and restoration, and priority evidence needs.

Key Messages

- A local site interacts with the wider landscape via emigration and immigration. This connectivity ensures passive restoration potential that can often depend on regional (and transboundary) recruitment. As such, a well-connected network includes multiple sites in a healthy condition with positive reproductive rates which may sustain sites which depend on immigration for persistence.
- Connectivity plays a key role in the success of restoration actions: understanding and ensuring potential connectivity of restored habitats is vital.
- Considerable knowledge gaps exist to evaluate passive connectivity as species dispersal traits for many species are (yet) poorly understood.
- Various approaches are available for prioritizing locations for restoration actions, ranging from expert knowledge, predictive models, to site-selection tools that can integrate information on connectivity and pressures.
- International cooperation to safeguard ecological and biological connectivity over large spatial scales is key to achieving successful ecosystem restoration outcomes in transboundary areas.

Connectivity is an essential part of the long-term survival and persistence of populations (e.g., metapopulations; Hanski and Ovaskainen, 2000). It is a process that can restore a declining population, re-establish a population after local extinction or degradation, maintain genetic diversity by gene flow, and support the flows of nutrients and energy (Arkilanian et al., 2020). Connectivity in the marine realm can be considered as diffuse, meaning that connections between for example, habitats, are not only defined based on their horizontal distance, but also in a vertical dimension and over time, particularly in relation to climate change (e.g., Dulvy, 2008; Doxa et al., 2022). Ensuring connectivity is a critical conservation challenge, as actions to improve connectivity within the marine realm are rare, and mainly related to removing pressures (e.g., shipping, fishing) that may degrade connectivity (Jorda et al., 2020). A connected system of restoration areas ensures the flow of materials, including energy, organisms, and/or genes, among habitat patches, ecosystems, or regions of interest. As connectivity is species-specific, and different species have different dispersal capabilities, there is no single solution on how to incorporate connectivity into restoration planning. In addition, food webs integrate community structure and ecosystem processes, and recovering trophic structure (vertical connectivity) through habitat restoration may be critical for long-term restoration success (Loch et al., 2020; Schlenker et al., 2024; Section 5.2.9).

Connectivity should be considered at the site selection stage of restoration planning to ensure that restored habitats are not isolated patches, but instead are linked together in a connected network of habitats that can support recolonization (e.g., Wang et al., 2024). In addition to improving critical habitat, restoration plans should include identifying and reconnecting fragmented habitats to improve overall ecological function (Rudnick et al., 2012).

Movement is a key property of connectivity, occurring over a range of spatial scales and can be active or passive; the former involving directed movement behaviour as seen in migration corridors (Bauer and Hoye, 2014). For example, while the latter involves transport by physical processes that displace organisms and their larvae or eggs (Arkilanian et al., 2020). In seascape ecology (refer to Section 3 footnote for definition) the physical fluxes that determine larval transport are referred to as "***structural connectivity***", i.e., a measure of the configuration and physical relation among patches of habitat in a seascape (Arkilanian et al., 2020). The physical oceanography, across scales, greatly influences connectivity not only through current-driven transport, but through the creation of barriers to movement. For example, the permanent halocline (vertical salinity gradient) of the Baltic Sea at ~70m depth effectively separates productive surface waters from the anoxic deeper water layers restricting the dispersal of species to upper oxygenated layers. The halocline creates a potential dispersal barrier for species dependent on more saline water (Schulz and Hirsche, 2007; Snoeijs-Leijonmalm and Andrén, 2017). Physical fluxes (currents) separate out water masses and influence the physical properties of the water column within the seascape, transporting pollutants, nutrients, organisms and propagules and creating chemical signatures that influence migration. Areas of upwelling are often highly productive and aggregative, and attract other activities (fishing, aquaculture, shipping, tourism, etc.) creating cumulative pressures (Pfaff et al., 2022). Physical fluxes may also promote ***retention***. Retention sites are areas where dispersal is localized (e.g., Wang et al., 2022), as well as places where anthropogenic pressures accumulate in the form of pollution (Pfaff et al., 2022). For species dependent on passive larval transport for dispersal, structural connectivity controls the degree of "***functional connectivity***", defined as the movement of adults, gametes or larvae across space, connecting populations and habitats (Hanski, 1998). In the marine context, both aspects are important considerations for restoration planning. ***Effective connectivity*** further depends on successful settlement and recruitment to the population, while ***genetic connectivity*** requires further survivorship of those settled larvae through to sexual reproduction (Pineda et al., 2007).

Ecological connectivity is a key element of the Kunming-Montreal Global Biodiversity Framework (KM-GBF) and its monitoring framework (see Section 4.1.2). In Target 2, connectivity is seen as a part of maximizing the benefits and outcomes of restoration for entire seascapes. The International Union for Conservation of Nature (IUCN) defines ecological connectivity as "the unimpeded movement of species, connection of habitats without hindrance and the flow of natural processes that sustain life on Earth" (Ament et al., 2023). Others have defined it as the degree of connection between similar natural environments present within a seascape, in terms of their components, spatial distribution and ecological functions (Arkilanian et al., 2020). Different analytical tools are available to model each of these aspects of connectivity and are briefly discussed below.

The distributions of marine benthic invertebrates on the continental shelves and slopes are rarely, if ever, homogenous over very small (Fraschetti et al., 2005) to very large spatial scales. Species distributions at regional scales are heavily influenced by environmental filtering, creating a habitat matrix that consists of uninhabited and low density areas between high density patches. For sessile and sedentary benthic species such as corals and sponges, connectivity within and among high density patches is a key process governing colonization, and hence important for shaping distributions and supporting habitat persistence and restoration (Taylor et al., 1993; Fontoura et al., 2022). In such species, connectivity is governed by larval transport, and is always region-specific, as connectivity is predominantly mediated through ocean bottom currents, which are in turn influenced by topographic forcing (e.g., Wang et al., 2020, 2021, 2022, 2024; Taboada et al., 2023). Together those physical elements, combined with larval behaviour (e.g., Gary et al., 2020), determine dispersal distances (Cowen and Sponaugle, 2009), while successful colonization has a large stochastic element due to generally high pre- and post-settlement larval mortality rates (Rumrill, 1990; Fraschetti et al., 2002). Many species, such as black corals and deep-sea sponges, are thought to have limited capacity for long-distance dispersal (Miller, 1998; Maldonado, 2006), while for others, larvae may persist for months in the water column (Hilário et al., 2015; Xuereb et al., 2018); although for most deep-sea species larval duration and even spawning season remain unknown (cf. Kenchington et al., 2019).

In the design of marine conservation and restoration interventions for benthic organisms, the consideration of sink / source dynamics can be a critical element to be considered. Both in the marine and in the terrestrial environments, sites are not equivalent to each other. Sources are defined as patches in which birth rates are greater than death rates and emigration rates are greater than immigration rates. Sink areas are habitats where birth rates are less than death rates and emigration is less than immigration. Therefore, a source is an area that, over a long period, shows no net change in population size and is a net exporter of individuals. Similarly, a sink is a net importer of individuals (Pulliam, 1988). Understanding source-sink population dynamics to implement both MPAs and restoration sites is a critical step. Recently, a good example of the importance that larvae produced in one MPA can drift beyond MPA borders and replenish populations in another well-placed MPA has been documented by Di Franco et al. (2012) where connectivity was recorded both from a MPA to unprotected areas and vice versa. The approach adopted in their study provides some of the first quantitative evidence of dispersal at both larval and post-settlement stages of a key species in Mediterranean rocky reefs.

Systematic Conservation Planning (SCP) offers a scientific process for improving spatial planning by identifying cost-effective conservation actions (Giakoumi et al., 2024), although it is under debate as to how to incorporate restoration into this process (Justeau-Allaire et al., 2023), and recent enhancements in restoration prioritization tools for supporting restoration have been developed, such as the restoptr R package, a tool for prioritizing restoration areas based on ecological and economic metrics to reach restoration targets. This tool aids in aligning restoration with broader conservation goals, such as biodiversity protection and ecosystem services enhancement. In this framework, connectivity is considered a core principle supporting SCP together with comprehensiveness, adequacy, representativeness, efficiency. Recently, the increased interest in incorporating connectivity into planning, with higher priority given to areas exhibiting strong ecological linkages, drove the development on new metrics allowing to improve the spatial prioritization process by protecting areas that present high connectivity values. Clusters of PUs that collectively exhibit high connectivity values can be identified by incorporating these metrics into spatial prioritization process, instead of prioritizing unique planning units (PUs). This allows accounting for properties of connectivity structure (i.e., densely connected sites) into final detection of areas of high conservation interest (Nagkoulis et al., 2025).

In the framework of active restoration, the establishment of well-connected sites combined with a steppingstone approach to further enhance the connectivity of restored sites should be introduced in restoration planning. Sources and destinations of larvae or propagules can be identified as separate spatial layers and taken into account in full-scale spatial prioritization involving other data on biodiversity, economic factors, human threats, and administrative constraints.

The current EU framework for the development of national restoration plans (see Section 4.7), separates out the plans for marine, terrestrial and freshwater ecosystems, yet these ecosystems are highly connected and in some cases the connections are essential for the persistence of some species and ecosystem functions (Beger et al., 2010). In particular, the necessity for both marine and freshwater habitats for salmonids and eels to complete their life-cycle, are examples of a rather large and high-profile ecosystem that are often the focus of conservation and restoration policies.

6.1 Why is Connectivity Important for Restoration and Recovery?

The Convention on Biological Diversity (CBD) summarizes the importance of ecological connectivity as: "The area, connectivity and integrity of ecosystems are essential for the protection of species and genetic diversity, ecosystem functioning and for the continued provision of ecosystem services. Ecological connectivity is important to maintain the integrity of ecosystems and to allow unimpeded movement of species within and across ecosystems and the flow of natural processes." (CBD/SBSTTA/24/3/Add.2/Rev.1)

Connectivity plays a crucial role in the success of restoration actions. If the habitats to be restored are poorly spatially associated – either horizontally (i.e., geographical distance exceeds species′ dispersal limits) or vertically (e.g., stratification, depth gradients), restoration may provide limited benefits. For instance, isolated habitats that lack structural connectivity with surrounding ecosystems may fail to sustain gene flow and therefore viable populations, making restoration efforts less effective. Similarly, habitats that are degraded and in poor condition may further limit recolonization potential, even when they are spatially connected.

For instance, in the Baltic Sea, the accumulation of deposited organic material on the seafloor can render those habitats unsuitable for species to attach to (e.g., Eriksson and Johansson, 2003). While these habitats may appear connected, their degraded condition can still prevent successful recolonization. If habitat degradation is not addressed first, their poor condition may hinder connectivity, reducing the effectiveness of restoration efforts. Restoration should therefore be targeted to areas where connectivity is already known to be sufficient, where habitats are in such condition to support recolonization, or where restoration actions can actively enhance seascape connectivity. The latter can only be achieved by removing potential dispersal barriers, which are often human activities that exert pressures that consequently degrade habitat condition, and thus also restoration potential.

Armoškaitė et al. (2021) demonstrate that assessing habitat composition, ecosystem functioning, and ecosystem service supply provides valuable insights into habitat-level connectivity. By linking changes in habitat structure to ecosystem services, the research highlights how environmental stressors—such as invasive species and eutrophication—impact marine protected areas (MPAs) and their ability to sustain biodiversity and ecological functions. By linking habitat structure changes to ecosystem service supply, alterations in species composition were shown to influence connectivity at the habitat level, affecting ecological functions such as nutrient cycling, filtration, and primary production. Armoškaitė et al. (2020) presented an ecosystem service assessment tool was applied to assess the impacts of environmental degradation on ecosystem service supply, demonstrating how habitat loss and species decline affect connectivity and the ability of marine ecosystems to maintain their functions. The tool applied a matrix-based approach and linkage diagrams to assess habitat loss, species decline, and connectivity disruptions.

While having the focus on marine restorations, the **source-to-sea approach** is important, particularly in some marine areas[10]. This approach recognizes the interconnectedness of different environments, such as land, river and sea (Mathews et al., 2019). The most significant factor deteriorating the ecological state of the Baltic Sea habitats is eutrophication (HELCOM ACTION, 2021). Various measures to reduce the nutrient loads in the catchment area are the most important ways for improving the state of the Baltic Sea in the long term. Therefore, there is a need to view the restoration beyond the sea area itself and widen the approach to land and sea interface. Additionally, condition of marine habitats can also be improved through local active restoration measures.

However, to ensure long-term restoration success, it is not only enough to restore habitats, as what happens after is equally important. Efforts to prevent further degradation in restored areas should be prioritized either through protection or restrictions on new developments. Without impact avoidance measures, ongoing or emerging pressures could counteract the benefits of restoration. Below we provide a few examples where connectivity has played a role in restoration and recovery.

6.1.1 Salmonids

Highly migratory species such as salmon (*Salmo salar*) and trout (*Salmo trutta*) depend on different essential habitats during their life cycle. Spawning and early years of the life cycle are spent in river or stream ecosystems, whereas the adult stage uses marine areas for feeding and growth (e.g., Lähteenmäki et al., 2025; Romakkaniemi et al., 2003). Therefore, ecological connectivity between the essential habitats is highly important for the salmon and trout. Annex III of the EU Nature Restoration Law lists both salmon and trout as key species for Article 5. For salmon and trout, active restoration measures will be made in the rivers they use as spawning areas, which connects to Article 7. A recent study on trout tagged with radio transmitters highlighted that migratory behaviour of sea trout was affected by migration season, flow conditions during the migration and migratory obstacles, such as dams (Lähteenmäki et al., 2022). Additionally, location of the spawning area had a significant effect on the movement activity of tagged trout. Identifying the bottlenecks for successful spawning, such as dams, and conducting active restoration measures to remove such barriers are key to support the life cycle of these migratory species and ensure effective restoration.

6.1.2 Mussels

In Europe, the *Mytilus* species complex plays a crucial role in coastal ecosystems and serves as a key model for studying marine connectivity. Despite their high dispersal potential, blue mussel populations exhibit significant genetic structuring and localized barriers, including small-scale geographical obstacles that impact gene flow even though they have a long pelagic larval duration. Along the North Atlantic coast and in the Baltic Sea, *Mytilus edulis, Mytilus galloprovincialis,* and *Mytilus trossulus* have undergone intraspecific vicariance events, emphasizing the need to understand population structures and dispersal patterns before implementing management strategies that preserve genetic integrity and ecosystem resilience (Gustafsson et al., 2024).

[10] Echoed in the "Ridge-to-Reef" (R2R) land/seascape approach (Guiang et al., 2021). R2R is a holistic, ecosystem-based management strategy that integrates terrestrial and marine conservation efforts, aiming to protect biodiversity and ecosystem services from "ridge" (uplands) to "reef" (coastal areas).

In the Baltic Sea and North Atlantic, blue mussels (*Mytilus* spp.) depend on larval dispersal to replenish depleted beds, maintaining genetic diversity that helps them adapt to changing environments. However, the invasion of the round goby (*Neogobius melanostomus*) has severely impacted mussel populations by intensifying predation, disrupting benthic ecosystems, and weakening essential functions like filtration and nutrient cycling. In some areas, overfishing of the goby has reduced its numbers, easing the pressure on mussel beds, but recovery has been slow and uneven. Small-scale dispersal barriers, such as those in the Skagerrak and the inner Baltic archipelago, further complicate this process, as isolated populations struggle to sustain themselves without external recruitment. Ultimately, full recovery has only been possible due to connectivity, as larvae from healthier populations drift into affected areas, replenishing local stocks (Skabeikis et al., 2018; Morkūnė et al., 2024). Protecting these natural connections is essential for conservation, ensuring that mussel populations remain resilient, ecologically functional, and capable of adapting to future environmental changes.

6.1.3 Deep-sea Sponges

Deep-sea sponge grounds meet the criteria for Vulnerable Marine Ecosystems (VME) developed by FAO in the International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO, 2009 (see also Section 4.7.1). The Northwest Atlantic Fisheries Organization (NAFO), has closed six areas to bottom contact fishing to protect these VME-types from significant adverse impact of bottom-contact fishing gears (Section 4.7.1). In NAFO, deep-sea sponge grounds are dominated by high biomass of large structure-forming demosponges (Order Tetractinellida, Suborder Astrophorina) that reach sizes of more than 25 cm diameter and constitute more than 99% of the total invertebrate biomass over extensive areas (Murillo et al., 2012). An increased level of biodiversity has been shown to occur in sponge grounds (Murillo et al., 2020a) which provide significant functions important in delivering ecosystem heath and services, such as water quality and biogenic habitat (Maldonado et al., 2015; Pham et al., 2019; Murillo et al., 2020b). Species distribution models for the sponge grounds and key sponge taxa (Section 6.2.1) have been developed for the area (Murillo et al., 2024) and the connectivity among the sponge habitats (Wang et al., 2024) and the closed areas (Kenchington et al., 2019) have been evaluated using particle tracking methods (Section 6.2.4). Passive restoration could occur in these closed areas.

As a consequence of the connectivity modeling, the six NAFO sponge VME closures were determined to be ecologically connected (Wang et al., 2024). The separate closures were therefore considered as a single interconnected system which collectively serve to sustain significant regional populations of sponge at levels which maintain their essential functional processes of value to the wider ecosystem. Ecological connectivity is one of the biodiversity attributes to be considered in the identification of Other Effective Area-Based Conservation Measures (OECMs) under the Convention on Biological Diversity (CBD) in their guidance on OECMs (CBD/COP/DEC/14/8). Based on connectivity evidence, NAFO considers the sponge closed area complex as a single OECM, and has submitted the network to the UNEP World Conservation Monitoring Centre.

6.2 Review of Methods Used to Assess Connectivity

All connectivity assessments begin by identifying the region of interest, followed by the selection of species, core habitats, links or movement paths between habitats, and then the application of connectivity analyses and models that support the prioritization of locations for protection or restoration across the region of interest (Arkilanian et al., 2020).

6.2.1 Selection of Appropriate Sites

For a restoration project to be successful it needs to be located in an area with suitable conditions to support the species or habitat. There are a number of methods available to identify potential sites including historical knowledge (Thursten et al., 2024) or expert opinion (Hunter-Ayad et al., 2020). Such approaches should take into account that conditions may have changed such that the area is no longer suitable (Thursten et al., 2024), e.g., due to sea level/climate change, removal of source populations, ecosystem being in a new alternative stable state, etc. There is a need to understand why the habitat/species disappeared in the first place. If this was due to anthropogenic pressures, have they been addressed? There is also a potential conflict with the current habitat - is this a conservation priority and would restoring the historical habitat result in the current habitat being lost?

Identifying locations of potentially suitable sites over larger spatial scales may rely on predictions from suitability modelling (Hunter-Ayad et al., 2020) or other methods (Wallace et al., 2010). Correlative suitability models are more common in marine systems than mechanistic or process orientated models (Melo-Marino et al., 2020). Many of the current uses of correlative distribution models in marine management focus on predicting present-day distributions of species/habitats, e.g., for conservation planning or designing monitoring strategies, or to project distributions due to climate change (Riess et al., 2015; Melo-Marine et al., 2020). However outputs from models aiming to predict present-day distribution may omit areas that are suitable but currently unoccupied, and these will be of most interest for restoration planning. Therefore, using correlative suitability models to identify appropriate locations for restoration may require changes to the usual approaches, e.g., in the selection of absences/pseudo-absences and thresholds (Lobo et al., 2010; Marcer et al., 2013) or explicitly including activities that are known to restrict the habitat or species of interest (Gonzalez-Irusta et al., 2022). Uncertainty associated with distribution maps should also be considered (e.g., Murillo et al., 2024; Section 5.1.6). Where multiple species are to be restored, stacked-distribution models can be helpful in locating areas of overlapping distribution. This approach has been used to identify locations for installation of man-made reefs for restoring structural habitat complexity and the associated biota in southern California (Zellmer et al., 2019).

The development of a correlative suitability model relies on species records. For marine benthic species, these are typically presence only data of sessile individuals/colonies, and do not include information on reproductive status. For some sessile benthic species, the environmental conditions required to trigger reproduction may differ from those suitable for growth and survival of the observed sessile life stages. For example *Ostrea edulis* is generally considered to require temperatures >15°C to induce spawning (although this varies between populations) but can survive and feed at lower temperatures (Bromley et al., 2016; Pogoda et al., 2023). Therefore, the outputs of correlative suitability models are those where mature individuals or colonies are able to survive and grow to a size that they are observed, but will not necessarily highlight locations with optimal conditions for reproduction. In addition, the environmental requirements for reproduction are largely unknown for many sessile benthic species (Montseny et al., 2021), limiting the extent that expert opinion can input into selection of locations where restored populations can both survive and reproduce. Without filling knowledge gaps on the life history of the species being restored (see Section 6.2.6), it might be difficult to select the most appropriate sites for restoration, leading to a risk that restored populations are reliant on influx of larvae from surrounding populations or continued active supplementation.

Once the set of locations of potentially suitable areas have been identified, their connectivity should be considered when selecting the most appropriate sites for restoration. Depending on the data available this may simply be relative size compared to other sites or proximity to other suitable areas (Langton et al., 2023). Ideally, the set of locations of potentially suitable areas could be incorporated into particle tracking models or agent based models (Section 6.2.4) to determine which locations may act as sources, sink or nodes in a wider network. For example, Millar et al. (2019), developed a distribution model for horse mussels to identify locations of suitable habitat. Particle tracking models were then implemented using known existing populations of horse mussel beds as particle release areas. Not all suitable patches were connected to these release areas, while some were connected to multiple sources. Suitable areas connected to multiple sources or that are key nodes in a network may be more appropriate for restoration activities than those with limited connectivity to other suitable locations.

Selecting suitable sites for restoration considering connectivity can be achieved using two main conceptual approaches. In the first approach, models are built that explicitly account for connectivity (e.g., agent-based models, Circuitscape) to simulate species dispersal and movement. Once connectivity patterns are modeled, restoration sites can be identified, e.g., using spatial prioritization tools, such as target-based minimum set planning tools (e.g., Marxan; Pressey et al., 1997) or balanced priority ranking (e.g., Zonation; Moilanen et al., 2022). In the second approach, critical habitats are identified across multiple species (e.g., with multi-species spatial prioritization framework), after which their connectivity is evaluated, and consequently their restoration needs (and possibilities).

Within the two approaches, information on habitat condition can be integrated to the site selection process, either by an additional species- or habitat-based condition information (by linking condition layers per species), or by informing of areas that are in degraded condition due to human activities and pressures (by introducing negatively weighted pressure layers). Regardless of methods used, site selection should include considerations of restoration benefits, in terms of, e.g., increased biomass, species richness, or improved ecosystem functionality, including the expected recovery time (Section 5). Feasibility of restoration actions, including their costs, should also be addressed, so that restoration actions are realistic and achievable.

6.2.2 Genetic Connectivity

Landscape genomics provides an opportunity to assess long-term functional connectivity by relating environmental variables to spatial patterns of genomic variation resulting from generations of movement, dispersal and mating behaviors (LaCava et al., 2021). Identifying seascape features associated with gene flow at large geographic scales for highly mobile species is becoming increasingly possible due to more accessible genomic approaches, improved analytical methods and enhanced computational power.

The genetic connectivity for fish can be expressed as differences in life-history traits that make species respond differently to the environment and pressures (i.e., Begg and Waldman, 1999). Different species and populations are genetically adapted to their environment and these adaptations are important to consider for restoration activities to be successful. In passive restoration, to be able to support species with local adaptations, and for active restoration, if restocking is part of the activity, to ensure that species and populations are adapted to the habitat they are introduced to are key considerations. Most species are easy to distinguish but for some species and especially at species population level, separation can be difficult or even impossible, and genetic methods are the only way to identify the connectivity of a specific species or population.

Genetic methods for identifying different populations have been applied for more than 50 years (Sick, 1965; see also Section 5.1.3). Genetic methods to provide evidence for stock mixing on, e.g., migratory grounds, elucidate population structure, and to estimate the relative proportions of stocks encountered in mixed-stock fisheries has in increasingly been employed (Reiss et al., 2009b; Ovenden et al., 2015). The reason for this genetic progression is the "genomic revolution," which has allowed the development of high-resolution genetic markers even for non-model organisms (Helyar et al.,2011; Nielsen et al., 2013).

6.2.3 Tagging Methods

Active connectivity refers to the phenomenon of the migration of marine species and marine organisms, and more specifically to "the movement of marine animals across the ocean and up and down through the water column" as referred in Johansen et al. (2021).

For highly mobile species such as **marine mammals, birds, and sea turtles**, a variety of tagging methods are commonly used to establish foraging movements and migration patterns, home range sizes and habitat utilization (Aarts et al., 2008; Bograd et al., 2010; Costa et al., 2012; Hussey et al., 2015; Harcourt et al., 2019; BirdLife International, 2023). A range of different tagging methods have been used. These include a) archival tags attached to an animal that record data for a pre-determined period and, on recovery, the stored data provide information on movements and behavior, and b) tags that transmit locations via radio or acoustic systems to a receiver usually on land or via an orbiting satellite.

Archival tags are generally used for animals that are easily recaptured - central place foragers such as breeding seabirds, pinnipeds or sea turtles. Transmitting systems historically relied on VHF but nowadays use satellites. ARGOS tags use the Doppler shift to estimate the position of the transmitter whilst FASTlock GPS systems now provide much more accuracy, with positions collected by the tag and shipped via satellite links (Dujon et al., 2014). These are often coupled with data logging systems to allow the collection of detailed behavioral (e.g., dive depth, swim speed) or environmental data (e.g. oceanographic sensors, CTD-SRDLs) from the animal.

Regular long-distance movements of many thousands of kilometres have been established for several species across taxa, e.g., leatherback turtles (Luschi et al., 2003), elephant seals (Hindell et al., 2016) and arctic terns (Egevang et al., 2010). Telemetry has been used to identify important feeding areas for seabirds (Wilson et al., 2009; Davies et al., 2021), marine mammals (Silva et al., 2013; Hindell et al., 2016), and sea turtles (Eckert, 2006; Fossette et al., 2010), resulting in several of these being designated marine protected areas (Wilson et al., 2009; OSPAR, 2023).

For **fish** species a range of different tagging methods have been used to study migration patterns; methods ranging from simple passive plastic tags (i.e., Peterson disc tag and T-bars to state-of-the-art electronic data recorders (i.e., Pop-up satellite archival tags (PSAT)). Passive plastic tags provide data on horizontal migration from A to B, time at liberty and other individual specific measures such as growth base on length and/or weight increment. The method is dependent on recapture. Thus, a rather intensive tagging program is needed to secure that useful data is coming out of the effort.

Acoustic loggers track movement of individual animals. The tag emits unique acoustic signals that are received by a submerged receivers placed at known locations. Acoustic telemetry is best utilized in freshwater, estuarine, and coastal habitats, and for long-term studies (Furey et al., 2024). Tagged animals are only detected when they are within range of the acoustic receivers. Another example of acoustic recording is for animals sending out acoustic signals on their own. In a study on the effects on harbour porpoise (*Phocoena phocoena*) of restoration of re-established stony reef in Northern Kattegat, Denmark, the acoustic activity of harbour porpoises in the area was recorded through passive acoustic monitoring (PAM) using timing porpoise detectors (T-PODs (Mikkelsen et al., 2013)

PSATs can provide detailed and unique insights into the swimming behavior of both large and medium-sized marine fish such as Atlantic halibut (*Hippoglossus hippoglossus*), Atlantic bluefin tuna (*Thunnus thynnus*), European eel (*Anguilla anguilla*), Atlantic cod (*Gadus morhua*), and Atlantic salmon (*Salmo salar*) (Aarestrup et al., 2009; James et al., 2020a; Lutcavage et al., 1999; Nielsen et al., 2023; Rikardsen et al., 2021). A case study on Atlantic cod (Nielsen et al., 2023) concluded that PSATs can successfully record high-resolution natural swimming behavior, including short, but biologically informative, events like predatory event or the outbreak from the cold-water intrusion, for 4–4.5 months, provide detailed information habitat preferences under the prerequisite that the cod are captured and released gently without any kind of barotrauma. Furthermore, it was concluded that physical tag retrieval is desirable and possible but should only be considered an option in inshore/coastal areas, where waters are more likely calm and drifting opportunities limited (Nielsen et al., 2023). Other tagging methods than the ones described in the examples are available. For further details on different tagging methods see Hüssy et al. (2020).

6.2.4 Connectivity Models

Lagrangian particle tracking (LPT) models are considered an important tool for assessing structural connectivity and potential functional connectivity and are especially valuable for applications in the deep sea (e.g., Xu et al., 2018; Kenchington et al., 2019; Zeng et al., 2019, Wang et al., 2020; Wang et al., 2021; Wang et al., 2022; Wang et al., 2024), where knowledge gaps and collection of samples can limit the use of other methods. In marine systems passive connectivity is heavily dependent on water velocities, and genetic isolation by distance is commonly seen in marine benthic invertebrate populations (e.g., Wright et al., 2015).

In LPT models, virtual particles are advected by the flow fields from numerical ocean models (Lange and van Sebille, 2017). Virtual behavior, if known, can also be added to the particles so that they can act as active drifters, i.e., swimming larvae. A number of user interfaces are available to assess oceanic structural connectivity. These combine complex individual-level models of particles with a 3-D oceanographic model of the physics, and can be used to run forward/hindcast simulations, habitat connectivity calculations, comparison of physical circulation models, etc.

Oceanographic models with current velocity products are available for the world's oceans (e.g., the "Nucleus for European Modelling of the Ocean" (NEMO) is a state-of-the-art modelling framework (Madec et al., 2024); https://www.nemo-ocean.eu), making this approach a viable one for most applications. Regional oceanographic models are preferred over the use of global models as they often more accurately reflect regional processes, and models with unstructured grids (mesh models) are often more accurate for coastal areas and archipelagos. Consideration of the appropriate ocean model products to use should include native resolution linked to the scale of physical processes that can be simulated, and level of ground-truthing with observational data.

LPT modeling has been used to evaluate the connectivity between closed areas to protect vulnerable marine ecosystems in the deep waters of the Northwest Atlantic Fisheries Organization (NAFO) regulatory area (Kenchington et al., 2019), which includes Flemish Cap and the Nose and Tail of Grand Bank east of Newfoundland and Labrador, Canada. LPT methods were also used to evaluate the connectivity networks between habitat patches of sponge grounds, sea pen fields, cold-water corals, bryozoan turf and stalked tunicate forests (Wang et al., 2024). There, properties of habitat configuration such as total habitat area, patch size, patch number and degree of isolation (Andrén, 1994), indegree (incoming connections) and outdegree (outgoing connections) (Arancibia and Morin, 2022) were evaluated, and simulations were preformed to examine the impact of removal of each patch from its respective network. These types of simulations can help with site selection in restoration planning.

Combining LPT methods with genetic methods (e.g., Taboada et al., 2023; Patova et al., 2025 and Wang et al., 2021) can be particularly valuable in identifying and explaining observed genetic patterns such as source-sink relationships which are critical for site selection in restoration projects. LPT methods can also help to evaluate habitat suitability models to determine the colonization potential of suitable habitat (e.g., Wang et al., 2022).

Agent-based modeling (ABM): Simulates the dynamics by representing the behavior of a collective (e.g. an aggregate of individuals) through an "Agent" that follows specific rules in each time step. Agents operate within a grid, where each grid cell has specific properties that affect the behavioral responses of the agents. The processes/behaviors affecting and effected by the agents have probabilistic components which randomize the dynamics (NAFO, 2019). Agent-based models require more data on the population dynamics of the "Agent" (See Section 5.3.1.3) but if necessary data are available, ABMs can evaluate recovery times and capture dispersal trajectories.

6.2.5 Food Webs

Community metrics and stable isotopes are the most common methods for assessing trophic interactions and will likely continue to be valuable tools when assessing how restoration activities impact an ecosystem (Loch et al., 2020). The recovery of food webs is further discussed in Section 5.3.2.

6.2.6 Knowledge Gaps

Evaluating connectivity in marine systems often involves modeling approaches, and having the information needed for producing connectivity models requires knowledge of species dispersal traits that is rarely available (e.g., spawning season, pelagic larval duration (PLD), swimming ability). For some of the Annex II habitats in the EU Nature Restoration law, this information is not available, or is not available under the physical conditions for the planned site(s). This is especially so for habitat 5, coral, sponge and coralligeneous beds, and for habitat 6, vents and seeps, although examples of connectivity assessments exist using various approaches (e.g., Jollivet et al., 2023; Mouchi et al., 2024). In these habitats even the species composition is often not well known. Further, many of the taxa have alternative reproductive modes, including asexual reproduction (e.g., sea grasses, marine plants, sponges etc.) and it is difficult to predict which modes of reproduction will be operative under specific environmental conditions. Nevertheless, given the importance of connectivity to the success of restoration plans, investments into evaluating connectivity over different spatial scales is justified.

6.3 Consideration of Connectivity in Active Restoration Plans

The Active Restoration Templates that we have reviewed (Section 7 and the report Annex 3) considered connectivity at a theoretical level and do not appear to have explicitly assessed connectivity in their planning at present. The Estonian-Latvian Interreg project: "Restoration and sustainable management of bladderwrack *(Fucus vesiculosus)* in the Gulf of Riga" considered the Sarema island *Fucus vesiculosus* population to function as a source to the southern part of Gulf of

Riga sink population. The source sites located around Sarema island are supported by better growth conditions, while sink sites in Latvian waters have growth conditions that are more demanding and suitable substrate distribution is more fragmented.

On an upcoming project in Norway there is a plan to restore Norway´s kelp forests (*Saccharina*) particularly in Skagerrak region where they have degraded due to sea urchin invasion. Norwegian Institute of Marine Research have been asked to make a plan for restoring Norway’s kelp forests by the Ministry of Trade, Industry and Fisheries. The action plan for this work will be made during 2026 and connectivity will be considered in relation to source populations for recovery of kelp.

The LIFE-IP BIODIVERSEA project is Finland's largest single investment in the protection of species and habitats in the Baltic Sea. The project includes objectives to improve the effectiveness of the protection of the marine environment and to promote the sustainable use of marine natural resources, as well as set targets for active restorations. The restoration objectives include, e.g., the restoration of 20 key species sites (e.g., for *Chara tomentosa*) and restoring 20 coastal lagoons important for fish reproduction. Connectivity is considered to some degree, e.g., in essential fish habitats the distribution of restored and already functional spawning sites are mapped to consider the movement range of the fish.

6.4 Obligation to Cooperate to Protect the Marine Environment

Restoration of habitats and species with large connectivity networks, spanning multiple jurisdictions, requires collaboration, coordination and cooperation between or among countries to ensure positive restoration outcomes. This role may be facilitated through Regional Seas Organisations (RSOs) where they exist (Section 4.6). RSOs provide an example of how cooperation to protect the marine environment can be operationalized at the regional level. As seen in Section 4 above, RSOs have adopted strategic plans with restoration targets. An example of taking connectivity into account in marine ecosystem restoration over large spatial scales can be found in efforts put in place under the OSPAR Commission for the restoration of eelgrass *Zostera* beds (OSPAR, 2024). In an OSPAR background report on best practices for the restoration of these eelgrass beds, it was emphasized that connectivity should be considered in the selection of restoration sites (OSPAR, 2024). The report further notes that: “Restoration planning should ideally consider connectivity among eelgrass beds, both locally and at the biogeographical level, and anticipate potential shifts in connectivity over time, notably in the context of climate change (Berkström et al., 2022). Given the evolving climate conditions, it may become necessary to consider the use of mixed populations or 'pre-adapted' donor beds to bolster ecosystem resilience, although it is important to note that our understanding of this research field remains limited (van Katwijk et al., 2016). To properly assess connectivity, a thorough grasp of the natural eelgrass bed locations in the area of interest is crucial. While most seeds typically only disperse a few metres from the bed, according to Källström et al. (2008) they may travel farther during storms, or while floating in seed pods. The connection with other eelgrass populations may prove pivotal for the ultimate long-term success of restoration efforts. It is in this context, factors such as climate change and coastal development can alter both connectivity and habitat suitability over time (Berkström et al., 2022). In addition, connectivity issues are also important in terms of non-indigenous species, pathogens and pollutants.” (OSPAR, 2024, p. 20).

The Helsinki Convention, which established the Baltic Marine Environment Protection Commission (HELCOM) is another RSO that seeks to protect the Baltic Sea from all sources of pollution from land, air and sea, as well as to preserve biological diversity and to promote the sustainable use of marine resources. In the centre of all HELCOM work is cross-border collaboration.

The HELCOM Working Group on Biodiversity, Protection, and Restoration (WG BioDiv) focuses on monitoring, assessing, and addressing nature conservation and biodiversity protection within HELCOM. WG BioDiv aims to strengthen the development of thematic assessment tools and provide a comprehensive evaluation of ecosystem health. Key action areas include Marine Protected Areas, Species and Biotopes, and Monitoring and Assessment. The group integrates technical and scientific outcomes from various expert groups and projects, covering eutrophication, hazardous substances, and biodiversity, while also incorporating relevant results from other subsidiary bodies, such as pressures from shipping, into a cohesive system.

WG BioDiv follows the PROTECT BALTIC project as a "steering group". PROTECT BALTIC ensures sufficient protection and restoration in the Baltic Sea's marine environment. The project aims to secure biodiversity, maintain ecosystem function, produce ecosystems services, and enable sustainable use. On the restoration component the project contributes to the development of reginal restoration action plan and is emphasizing regional priorities, methods, costs and feasibility.

The importance of building the national restoration plans based on knowledge exchange between with neighbouring countries has been noted. This is particularly true in the case with mobile species. These examples illustrate the need to cooperate and how cooperation can be achieved to protect the marine environment, as reflected in Article 197 of UNCLOS, including through restoration efforts. UNCLOS establishes the duty to cooperate to protect the marine environment and highlights the role of competent organizations in operationalizing this obligation. Article 197 of UNCLOS establishes that "States shall cooperate on a global basis and, as appropriate, on a regional basis, directly or through competent international organizations, in formulating and elaborating international rules, standards and recommended practices and procedures consistent with this Convention, for the protection and preservation of the marine environment, taking into account characteristic regional features" (UNCLOS, 1982; Art. 197). As seen in Section 4 above, the obligation to preserve the marine environment under Part XII of UNCLOS may also encompass the obligation to restore marine ecosystems (ITLOS, 2024). In this recent advisory opinion on climate change and international law, ITLOS emphasized that "the duty to cooperate is reflected in and permeates the entirety of Part XII of the Convention" (ITLOS, 2024, para. 297). In the South China Sea Arbitration, the Permanent Court of Arbitration (PCA) highlighted that the importance of cooperation to marine protection and preservation has been recognised by ITLOS multiple times (PCA, 2016, para. 985). The PCA has also noted that in the Pulp Mills on the River Uruguay case, the International Court of Justice (ICJ) has recognised that "by co-operating … the States concerned can manage the risks of damage to the environment that might be created by the plans initiated by one or [the] other of them, so as to prevent the damage in question" (PCA, 2016, para. 985; see also ICJ, 2010, para. 77).

7 Active Restoration Initiatives

This section corresponds to WKREST ToR e) Summarise available and proposed measures and potential threats to achieving the active restoration of marine habitats, their state of development (e.g. from experimental to large-scale trials and applications), relative benefits and costs, and effectiveness. Identify additional evidence needs to evaluate the costs and benefits of active restoration.

Key Messages

- A clear end point/target for active restoration is key to successful planning. Ecosystem restoration should be the focus, including functions, services and aim to self-sustainability and resilience.
- Development of a strategy for of a well-structured project will include site selection and methodologies for implementation.
- Monitoring and adaptive management/maintenance shall be implemented while aiming for a self-sustaining environment.
- Evaluation on the success of active restoration projects should also include consideration of failures/lessons learnt. If results are different than planned, there is a possible need to reframe how success is defined.
- A strategic and inclusive approach is important for successful restoration. While a strategic top-down approach to planning is necessary to stick to sound and scientific methodology, the implementation and success will rely on the buy in of stakeholders and the wider society. Early engagement for implementation and support throughout the whole duration will then be key to a successful project.

7.1 Summary

The general impressions about active restoration, as derived from the information we shared during the WKREST workshop, are as follows:

- In this chapter we use the following definition of active restoration: Active nature restoration is an action that re-establishes/restores natural habitats, hydrological processes, biological mechanisms and/or populations where they had known occurrences;
- In Europe, large scale active nature restoration is comparatively in its infancy, with few projects carried out in the last decade and many ongoing or in progress. In comparison there is a large body of evidence on nature restoration from North America and Australia;
- European active nature restoration projects span large gradients in environmental characteristics like water depth (coastal to deep sea) and salinity as well as in terms of habitat forming species, habitat types and target organisms. The main policy driver for nature restoration in the EU will be the Nature Restoration Regulation;
- It is key to adopt systematic conservation planning;

- In projects it is key to define targets and aims, timescales and thresholds for success for the chosen attributes (e.g., habitats, functions, services, species) provided by the restored system;
- Proper site selection includes documentation of historical occurrence of the suitable habitat and assessment of current environmental conditions and, also, includes mapping of key pressure factors, mapping of other use of marine space and options for protection of the restored habitat/species. Site selection should also include considerations regarding connectivity;
- Monitoring programs following the restored habitats and species are key to assessing the success or reasons for failure of the projects in relation to invested resources and achievement of defined goals and expected ecosystem services. Monitoring programs shall consider relevant temporal and spatial scales.

7.2 Goals/Aims of Active Restoration Measures

The general goal of active restoration measures is to reestablish a functional, self-sustaining habitat. The "International principles and standards for the practice of ecological restoration" (Gann et al., 2019) documents guidelines for restoration practitioners to restore degraded ecosystems. An essential part of a restoration project and one of their key principles is the clear definition of one or more high level targets that identify the ecosystem to be restored (as informed by a specified reference ecosystem). Although the ecosystem is targeted, the specific restoration action may concern a species that is keystone or foundation to the habitat/ecosystem. The goals and objectives narrow down the aims and are used to monitor the progress of the restoration project over time, which will enable adaptive management approaches to be applied when necessary. Specific objectives are comprised of several ecosystem attributes that are monitored through specific indicators. Full recovery is defined as the state or condition whereby, following restoration, all key ecosystem attributes closely resemble those of the reference model (Gann et al., 2019). Different stakeholders should be involved in the definition of the different targets, goals, objectives, and methods of implementation and monitoring.

7.3 Restoration Strategies and Planning

A strategic approach to the restoration process is essential to ensure its success, particularly given the challenges of high ambitions often being met with limited financial resources. Balancing the need for central strategic organization with the importance of community involvement is critical, as is engaging various stakeholders at the earliest stages of planning. During WKREST, examples were given of how such a strategy was developed in Italy and in Scotland.

A well-structured strategy offers multiple benefits, starting with an established methodology, i.e. site selection tools, to identify suitable restoration sites including documentation of historic occurrence – although care needs to be taken when applying this approach (see section 6.2.1). One approach being planned in Scotland involves the initial exclusion of areas where current environmental characteristics are incompatible with species survival and reproduction, narrowing the focus to locations where there is a reasonable chance of restoration success. Data gaps can then be addressed in targeted areas as the process progresses. Working with macroalgae forests at the basin scale in the Mediterranean, Fabbrizzi et al. (2023) used systematic conservation spatial planning tools to assess achievement of restoration targets. This included looking at different planning scenarios and restoration targets in line with the EU Biodiversity Strategy for

2030. Results show that the number of suitable sites for restoration is very limited at basin scale, and only the recovery of 10% of regressing and extinct macroalgal forests can be planned.

Once potentially suitable sites are identified, conducting both strategic environmental and socio-economic impact assessments is crucial. Strategic environmental impact assessments will include mapping of pressure factors and how these can be handled in order to avoid jeopardizing restoration efforts. These assessments help balance conservation objectives with sustainable use potential, ensuring maximum benefits for nature while minimizing socio-economic conflicts and enhancing social buy-in. Additionally, a strategic approach enables the efficient allocation of funds to projects with the highest potential for success, optimizing resource use.

Inclusivity is another key advantage, as bringing stakeholders together is often a determining factor in a project's success. Early collaboration can also facilitate voluntary protection measures for active projects before a more stable form of legal protection is implemented, contingent on the success of the restoration efforts.

Furthermore, strategic planning allows for the potential colocation of restoration projects with existing protected areas. By linking new initiatives to existing protection of species and habitats, it is possible to leverage established conservation frameworks, reduce the overall footprint, and address spatial constraints arising from the increasing number of ocean users.

Finally, valuing ecosystem services and incorporating non-market values and uncertainties into decision-making can ensure that restoration efforts align with societal interests. Studies such as Hynes et al. (2021) highlight the marginal societal willingness to pay for the ecosystem services associated with kelp forest restoration, while research by Chen et al. (2022) suggests that large-scale deep-sea ecosystem restoration can be economically viable in terms of welfare improvement, even when costs are high. These insights underscore the broader societal benefits of a well-planned, strategic approach to restoration.

7.4 Potential Threats and Barriers to Active Restoration Measures

Potential barriers in the field of ecosystem restoration include legal barriers (favoring traditional conservation) and restrictions on obtaining permits, especially when considering large scale or landscape restoration (Foster and Bell-James, 2024). Protection-based measures have not yet been fully implemented; those currently in place mainly focus on passive restoration, such as management measures in marine protected areas, rather than on active restoration initiatives. Yet, the instalment of marine protected areas is an important condition for successful restoration. Additionally, there is a need to incorporate climate change considerations into restoration efforts as already described in the EU Nature Restoration Law where restoration is a contribution to the EU's climate mitigation and adaptation objectives. Another critical barrier is the absence of legal guidance on implementing measures that create suitable habitat conditions for the long-term success of restoration projects. For instance, artificial oxygenation could potentially serve as a crucial function in facilitating ecosystem recovery. No clear regulatory framework governs its application, nor is it systematically integrated into environmental monitoring frameworks. Factors of failure and success related to the abiotic and biotic environment have been mentioned elsewhere in this report.

7.5 Evaluation of the Success or Failure of Active Restoration

A global review of active restoration outputs (success and failures) across marine and coastal habitats (Fraschetti et al., 2021) shows that *where* the restoration activity is undertaken is more relevant to a successful outcome than *how* (method) the restoration is carried out. Most studies used transplantation techniques in combination with use of nurseries and artificial structures (~40%). Planting and the modification of physical/hydrological settings were also common (20 and 25%, respectively). A total of 228 species belonging to 118 genera have been targeted by active restoration interventions with majority of studies recorded in estuarine/wetland systems (42%), followed by intertidal and subtidal rocky reefs (30%), and soft-bottom environments (28%). Across all habitats, 60% of the studies were classified as successful and a further 15% as partially successful. This pattern was consistent across habitats independently from the number of studies.

The main reasons of failure (10% of studies) were very heterogeneous and include inadequate site selection and methodology. A substantial lack of knowledge on the factors driving restoration success together with the absence of protocols and best practices for supporting the recovery of ecosystems were found to be major issues across studies.

A standardized approach for defining "success", i.e., specific indicators and predetermined threshold values for "success," "partial success," and "failure" is currently lacking in many cases with the majority of cases using measures of survival or growth without defined and measurable *a priori* targets, or reference sites (Fraschetti et al., 2021). Gann et al. (2019) provide guidance and examples on attributes to be used to assess and evaluate restoration outcomes. These may include simple metrics of survival, cover, structural complexity, ecosystem function, and ecosystem services as well as projection of improvements in time (e.g., within first 1-3 years, 20 years and so on).

MERCES (EU H2020 project), AFRIMED (EU CINEA project) and various LIFE projects have worked on best practices (including on site selection, historical and current presence and threats, monitoring, success evaluation), and restoration prioritization frameworks for macroalgae (Smith et al., 2023; Fabbrizzi et al., 2023).

An important part of success evaluation is the monitoring of restoration outcomes over time and a variety of methods and technological tools are available including scuba diving, the usage of drones to assess the increase in coverage of transplanted species in shallow waters to highly specialized automated vehicles (AUVs, landers with docked crawlers and AUVs, crawlers with robotic arms), high resolution mapping, and innovative sensors and real life remote data transmission (Aguzzi et al., 2024).

7.6 Active Nature Restoration Projects

Most projects presented at WKREST are just starting and/or experimental. Many planning studies are being undertaken, and projects are relatively small (several km^2 scale maximum), trying out techniques and approaches. Plans include reduction of relevant pressures by human activities, species/habitats and areas selection, terrain surveying, methodology development and technical design and monitoring planning. Besides, in many cases financial support is still being sought and the process of involving stakeholders was started relatively recently. Given this, there is still too little insight in factors leading to success or failure, the actual benefits and/or recovery times.

Most current projects take place in coastal areas, focusing on characteristic species and habitats for the respective areas, like shellfish reefs, seagrass, macroalgae (kelp, *Cystoseira*, *Fucus*), red coral, fan mussel and salt marshes (UK, Denmark, Finland, Latvia, Portugal, Norway, Spain, France, Italy, Slovenia, Croatia, Greece). Open sea projects are rarer, but also starting up, focusing on species like cold water coral, horse mussels, sea-pens and burrowing megafauna, and flat oysters (The Netherlands, Belgium, Germany, Denmark). A special case is the deployment of boulders, where these were once fished away on a large scale (Denmark).

Nearshore and offshore measures include active restoration of ecological functions, e.g. fish spawning grounds (Baltic) by removing reed, active introduction of the brackish water algae *Chara tomentosa* in the Baltic (Finland), actively introduction of kelp and *Cystoseira* forests (Norway and the Mediterranean) by putting pre-seeded stones back in the water, restoration using different methods of seagrass (Scotland, England, Denmark), brown algae (*Fucus vesiculosus*) in the Baltic (Latvia). Furthermore, activities include active restoration of boulder reefs (Denmark), horse mussel reefs (Denmark) and blue mussel reefs (Denmark). Also, seascapes restoration (DK) and multispecies restoration are taking place. Offshore flat oyster restoration is under development using remote setting methods: substrate (stones, tiles) with oyster spat are applied to the seafloor. MERCES (EU Horizon 2020 Project 2017-2021) worked on many nearshore and offshore sites across the European seas, aimed at recovery potential and protocols for active restoration of different habitats and species including seagrass (e.g. *Zostera* and *Posidonia* planting), *Pinna nobilis* (transplantation), macroalgae, kelps, corraligenous species (e.g., planting red coral and sponges) but also deep sea corals (transplantation and attachment of cold-water coral fragments to either natural or artificial substrates) (Bekkby et al., 2020; Ederey et al., 2025; Montseny et al., 2019; Villechanoux et al., 2022).

Deep sea nature restoration is also happening: deep sea corals restoration by a combination of protection measures (e.g., excluding fisheries) and introducing (pre-colonized or not) concrete reefs, 3D-printed reefs, or metal frames, by releasing corals and other sessile species attached on suitable materials (badminton method) (e.g., attached to rocks or biodegradable attachment points) (MERCES and REDRESS projects, sites in Spain, Portugal, Italy, UK, Ireland, France, Montseny et al., 2021).

Techniques often encompass reintroduction of target species where these have disappeared, where necessary together with substrate to optimize colonization. Supporting measures mentioned are:

- Reduction of pollution there where this may hamper restoration, such as nutrient influxes to eutrophicated habitats;
- Eradication of predators on target species, e.g., dosing quicklime to eradicate sea urchins predating kelp in Norway or culling sea urchins to trigger the process of recovery of persistent barren grounds in Italy;
- Oxygenation of water layers near the seafloor, as measure against anoxic and hypoxic conditions, but also to counteract the release of nutrients from (anoxic) sediments.

At WKREST it was discussed (but not concluded) whether supportive measures can be seen as 'nature restoration measures' per se, or only as nature mitigation or enhancement. This is relevant for the decision whether to include these as opportune measures in the EU Nature Restoration Regulation. The definition of 'restoration' in the NRR in this sense is wide ranging: '*restoration' means the process of actively or passively assisting the recovery of an ecosystem in order to improve* *its structure and functions, with the aim of conserving or enhancing biodiversity and ecosystem resilience, through improving an area of a habitat type to good condition, re-establishing favourable reference area, and improving a habitat of a species to sufficient quality and quantity in accordance with Article 4(1), (2) and (3) and Article 5(1), (2) and (3), and meeting the targets and fulfilling the obligations under Articles 8 to 12, including reaching satisfactory levels for the indicators referred to in Articles 8 to 12*.

Clarification of what can be seen as restoration in practice by the European Commission is advised and expected as the work of the New Expert Group on NRR progresses and national restoration plans are drafted by Member States.

Two major European sources of funding that have some targeted funding towards restoration include the Horizon and LIFE programmes. Horizon ('2020', latterly 'Europe') is the EU's key funding programme for research and innovation. The LIFE programme is the EU's funding instrument for the environment and climate action with more regional or subregional actions. The projects funded have started with feasibility studies, pilot studies or development works moving towards scaling-up research actions. European restoration projects funded between 2017 and 2022 can be found in the World Global Marine Restoration Database (https://restorationfunders.com/ecosystem-restoration), including 50 marine-related restoration projects.

7.7 Examples of Active Nature Restoration in Europe

In WKREST a few active restoration measures were presented by the participants to get an impression of the different approaches in different countries and for different assets. The examples are described below and summarized in Table 7.1. This list reflects the projects the participants of WKREST are involved in and is therefore not exhaustive and mainly Europe focused. In addition, Annex 3 presents four active restoration projects, each described using a completed template developed in preparation for the workshop. These templates can help identify commonalities and differences across projects and assess best practices.

Table 7.1. Active restoration measures presented by WKREST participants to get an impression of the different approaches in different countries and for different assets.

Stage	Ecosystem component	Area	Country/region	Measures	Project name and links to websites and literature
Started	Breeding birds	Coastal	Finland	Eradication of alien predators, such as Racoon Dog and American Mink	Biodiversea LIFE-IP (https://www.metsa.fi/en/project/biodiversea-eng/)
Started	*Chara tomentosa*	Coastal	Finland	Reintroducing species to areas, from where they have disappeared.	Biodiversea LIFE-IP (https://www.metsa.fi/en/project/biodiversea-eng/)
Started	Coastal lagoons	Coastal	Finland	Measures include mainly restoring dredged thresholds or opening of the channel, which has been impeded due to human activities	Biodiversea LIFE-IP (https://www.metsa.fi/en/project/biodiversea-eng/)
Started	Estuaries	Coastal	Finland	Reforming the modified deltas towards a more natural state.	Biodiversea LIFE-IP (https://www.metsa.fi/en/project/biodiversea-eng/)
Started	*Fucus* restoration	Coastal	Latvia	Different restoration methods will be tested	FUCUS (https://lhei.lv/en/restoration-and-sustainable-management-of-bladderwrack-fucus-vesiculosus-in-the-gulf-of-riga-fucus/)
Started	Kelp	Coastal	North Norway	quicklime to remove grazers (sea urchins)	From sea urchin desert to lush kelp forest (https://www.hi.no/hi/nyheter/2024/november/fra-krakebolle-orken-til-frodig-tareskog) (Christie et al., 2024)

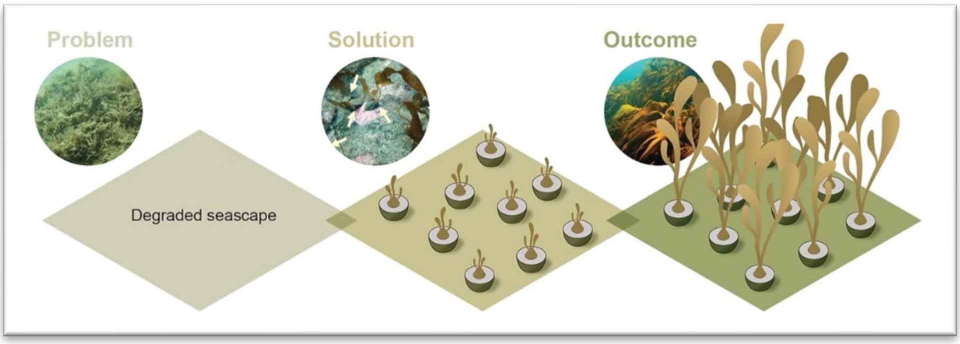
Stage	Ecosystem component	Area	Country/region	Measures	Project name and links to websites and literature
Started	Kelp	Coastal	Norway	Seeding out kelp on small stones (Green gravel)	Kelp Restoration | Green Gravel (https://www.greengravel.org/) (Fredriksen et al., 2020)
Started	Kelp	Coastal	Norway	Artificial reefs as substrate and habitat for fish	Strand, HK. 2019. Porsangerfjorden 2.0. Rapport fra havforskningen 2019-7 (in Norwegian with English abstract)
Started	Kelp	Coastal	South Norway	Future proofing of kelp	GEcoKelp | Home
Started	Kelp, maerl, native oyster, horse mussel, sea pens and burrowing megafauna	Coastal	England	Restoration potential	MaRePo+ Marine Restoration Potential plus (MaRePo+) - MF6006 (https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectId=21682)
Completed 2021	Kelp, Zostera/mussels, *Posidonia*, Red Coral, Pinna, *Cystoseira*, Deep-sea corals	Coastal	Norway, Finland,, Netherlands, Azores, Spain, France, Italy, Croatia,	Transplants of macroalgae and seagrass. Shallow waters. Coralligenous sponge and coral diver transplants. Lander transplants and badminton release of coral and sponges from fisheries bycatch,	MERCES EU Project (site no longer active), Fraschetti et al., 2021 ; Bekkby et al., 2020 ; Montseny et al. 2019, 2021; Edery et al., 2025; Villechanoux et al., 2022
Completed 2022	Macroalgae - Cystoseira	Coastal	Spain, France, Italy, Greece, Morocco, Tunisia	Transplants of stones with Cystoseira germlings. Shallow waters	AFRIMED (www.afrimed-project.eu)

Stage	Ecosystem component	Area	Country/region	Measures	Project name and links to websites and literature
Finalized and ongoing	Multi habitat type restoration in the same area	Coastal	Denmark (several locations)	Re-establishment of boulder reefs, eelgrass beds and blue mussel beds	Multihabitat restoration in Vejle Fjord (https://www.vejleaadalogfjord.dk/interessenter/projekter/english)
Started	Saltmarsh, seagrass, native oyster beds	Coastal	England	Restore habitats	ReMeMaRe Restoring Meadow, Marsh and Reef (ReMeMaRe) | Estuarine & Coastal Sciences Association
Ongoing	Seascape restoration	Coastal	Limfjorden, Denmark	Coastline protection through restoring coastal habitats	COASTaL life (https://www.coastal-life.dk/en/)
Started	*Zostera marina*	coastal	Finland	Reintroducing species to areas, from where they have disappeared.	Biodiversea LIFE-IP (https://www.metsa.fi/en/project/biodiversea-eng/)
Started	*Zostera marina*	Coastal	England	Re-establish seagrass beds	ReMEDIES (https://saveourseabed.co.uk/the-project/project-overview/)
Started	Seagrass	Coastal	Portugal	Re-establish seagrass beds, conserve additional area and remove invasive species	LIFE-RESTORESEAGRASS (Marine Forests - Restore Seagrass)
Finalized and ongoing	Boulder reef restoration	Coastald and offshore	Denmark (several locations)	Re-establishment of lost boulder reefs by deploying stones originating from land	Stone reef projects (https://www.danishmarinerestoration.com/marine-restoration/stone-reefs/)

Stage	Ecosystem component	Area	Country/region	Measures	Project name and links to websites and literature
On-going or planned 2024-2028	Cold water corals (*Madrepora pertusa*)	Deep sea	Iceland, Ireland, UK, France, Italy	3D printed and artificial reefs and metal frames with or without coral nubbins	REDRESS (www.redress-project.eu)
On-going 2024-2028	Gorgonians and corals	Deep sea	Azores	Bioreleases on stone substrate (badminton method) to coral and sponge gardens from fisheries bycatch	REDRESS (www.redress-project.eu)
On-going 2024-2028	Gorgonians, pennatulids and sponges	Deep sea	Spain	Bioreleases on stone substrate (badminton method) to soft sediments from fisheries bycatch	REDRESS (www.redress-project.eu)
Ongoing	Horse mussel and native oyster	Offshore	Denmark	Development of disease spat production and deployment methods	BioReef: marine restoration in Danish waters (https://wwf.panda.org/act/partner_with_wwf/corporate_partnerships/who_we_work_with/orsted/bioreef/)
Ongoing	oysters	Offshore Nearshore	Netherlands, Belgium, Germany Most European countries	oyster pilots in offshore windfarms and N2000 areas N2000 areas and other MPA's	NORA – Native Oyster Restoration Alliance (https://noraeurope.eu/) NERA – NL reef restoration alliance(www.nera.nu)

Stage	Ecosystem component	Area	Country/region	Measures	Project name and links to websites and literature
Completed 10/2023-10/2024	Reoxygenation of low oxic coastal marine environment	Offshore	Baltic Sea	preparation of demonstrator project	BOxHy - https://flexens.com/wp-content/uploads/2024/11/BOxHy_Report_FINAL_2024.pdf
Planned 2024-2028	*Stichopus* and *Nephrops*	Offshore	Sweden (Kattegat)	Bioreleases to soft sediments from fisheries bycatch	REDRESS (www.redress-project.eu)

7.7.1 Restoration Methods for Kelp in Norway

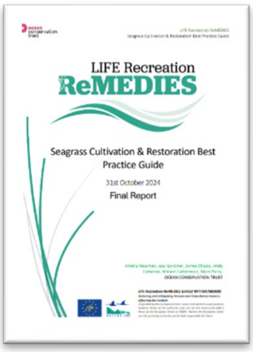
Project	Green Gravel
By	Kjell Magnus Norderhaug IMR Norway
Feature	Kelp restoration
Country	Norway
Measures	The Parliament of Norway requested 789 (2024) a plan for restoring Norway's kelp forests in order to achieve improved ecological status. **Quicklime to remove sea urchins.** In 2013, a large scale (70 hectare) kelp forest restoration experiment was conducted in a sea urchin barren that had been stable for 45 years. 200 tons of quicklime was used to eradicate the sea urchin population. Kelp recovered within a year in the lime-treated sites (Christie et al., 2024). **Green gravel (seeding kelp onto small stones):** Green Gravel is a technique for restoring kelp forests. It involves seeding small rocks or line with kelp propagules, rearing them in the lab and then out-planting them into the field. The juvenile kelp overgrow or move off the gravel and attach to the underlying reef. This technique is cheap, simple, and does not require scuba diving, highly trained field workers, or engineered structures. The gravel can be scattered from a boat and can be up-scaled to treat large areas.  (source: https://www.greengravel.org/) **Artificial reefs.** Rope based artificial reefs have successfully been tested as substrate for kelp, as they lift them above the sea floor (hanging gardens). These reefs also increase survival of juvenile fish. **Future proofing of kelp**. Ongoing research in the NRC project GecoKelp explores links between intraspecific genetic variation in kelp and environmental conditions. If genotypes robust against marine heatwaves can be identified, they can be seeded into local populations to increase population resilience.
Read more	Kelp Restoration | Green Gravel Christie, H., Moy, F.E., Fagerli, C.W. *et al.* 2024. Successful large-scale and long-term kelp forest restoration by culling sea urchins with quicklime and supported by crab predation. *Mar Biol* 171: 211. https://doi.org/10.1007/s00227-024-04540-0

	Fredriksen, S., Filbee-Dexter, K., Norderhaug, K.M. *et al.* 2020. Green gravel: a novel restoration tool to combat kelp forest decline. *Sci Rep* **10**: 3983. https://doi.org/10.1038/s41598-020-60553-x Strand, H.K. 2019. Porsangerfjorden 2.0. Rapport fra havforskningen 2019-7 (in norwegian with English abstract) GEcoKelp | Home Wood, G.V., Griffin, K.J., van der Mheen, M., Breed, M.F., Edgeloe, J.M., Grimaldi, C., Minne, A.J.P., et al. 2024. *Reef Adapt: A tool to inform climate-smart marine restoration and management decisions*. Communications Biology, 7: 1368. doi.org/10.1038/s42003-024-06970-4. https://www.reefadapt.org/

7.7.2 Restoration of *Fucus vesiculosus* in the Gulf of Riga

Project	FUCUS (Restoration of Fucus vesiculosus in the Gulf of Riga)
By	Ingrīda Andersone
Feature	Bladder wrack *(Fucus vesiculosus)*
Country	Latvia
Measures	The decline of brown algae *Fucus vesiculosus* in the Baltic Sea was observed over several decades. The Gulf of Riga is not an exclusion. Due to eutrophication and climate change induced browning of water the rapid *Fucus* decline was observed. Project FUCUS is focusing on finding suitable methods of restoration in different environmental conditions in the Gulf of Riga. Restoration is planned at 2 pilot sites in the southern part of the Gulf of Riga (Latvian territory) and 2 pilot sites in the northern part of the Gulf of Riga (Estonian territory).
Read more	https://lhei.lv/en/restoration-and-sustainable-management-of-bladderwrack-fucus-vesiculosus-in-the-gulf-of-riga-fucus/

7.7.3 Seagrass restoration in England

<table>
<tr><th>Project</th><th>ReMEDIES</th></tr>
<tr><td>Feature</td><td>Seagrass (Zostera marina)</td></tr>
<tr><td>Country</td><td>England</td></tr>
<tr><td>Measures</td><td>Active restoration of seagrass beds through the cultivation of seed from healthy beds. Seagrass Mat Technology (SMT) was used to grow seagrasses in cultivation facilities, which were later translocated with established plants. To support the survival of the transplanted seagrass, a voluntary no anchor zone was implemented. In addition, Advanced Mooring Systems were installed to reduce the physical pressure to the seabed.

</td></tr>
<tr><td>Read more</td><td>ReMEDIES Best Practice Report Full</td></tr>
</table>

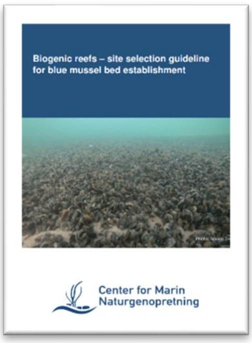
7.7.4 Estimating Habitat Restoration Potential

Project	MaRePo+ (Marine Restoration Potential and enhancement project)
Feature	Kelp, native oyster (*Ostrea edulis*), horse mussel beds (*Modiolus modiolus*), sea-pens, burrowing megafauna
Country	England
Measures	Marine Restoration Potential plus – This project adds to the MaRePo. It maps key habitat potential for kelp, native oyster, horse mussel beds, and sea-pens and burrowing megafauna. The constraints to restoration potential are also mapped, which covers hard constraints (activities or infrastructure that prevent habitat restoration) and soft constraints (activities and legislative frameworks that would not prevent restoration but may influence feasibility, deliverability, success). In addition, it examines the use of climate change projections for prioritisation of habitat restoration.

7.7.5 Restoration of Boulder Reefs in Denmark

Project	Boulder restoration Denmark
By	Jens Kjerulf Petersen DTU Aqua, Denmark
Feature	Boulders (abiotic reefs)
Country	Denmark
Measures	**Description.** A very conservative estimate indicates that merely in the 19th hundreds more than 8 million m3 of stones were removed from the seafloor and in particular in shallow areas, thereby removing important substrate for seaweed forests. In Denmark, several projects have been developed and carried out to restore lost boulder reefs and is so far the preferred active nature restoration measure in past and present projects.  **Project phases.** Based on experience from various projects, a boulder project includes definition of purpose, a site selection process containing: Historic occurrence, environmental conditions, associated nature values (connectivity) and protection measures and recommendations for best practice and follow-up monitoring to assess project success and ecosystem services provided.
Read more	Dahl, K., Stæhr, P.A.U., Göke, C., Svendsen, J.C., Steinfurth, R.C.H. and Jørgensen T.B. 2024. Best practice for boulder reef restoration. Scientific report from the National Centre for Marine Nature Restoration. https://www.danishmarinerestoration.com/media/72639/stenrev-best-practice.pdf Helmig, S.A., Nielsen, M.M. & Petersen, J.K. 2020. Andre presfaktorer end næringsstoffer og klimaforandringer – vurdering af omfanget af stenfiskeri i kyst-nære marine områder. DTU Aqua-rapport nr. 360-2020. Institut for Akvatiske Ressourcer, Danmarks Tekniske Universitet. 24 pp.

7.7.6 Multi-habitat Type Restoration in Denmark

Project	Multi-habitat restoration Denmark
By	Jens Kjerulf Petersen DTU Aqua, Denmark
Feature	Blue mussel beds (*Mytilus edulis*), eelgrass beds (*Zostera marina*) , boulders (abiotic reefs)
Country	Denmark
Measures	  **Description.** In several restoration projects, several habitat types like blue mussel beds, eelgrass beds and boulder reefs are restored in the same area in various combinations of the three habitat types. Some are restored to create synergies between ecosystem services, others to generally improve ecological conditions in a local area. **Project components.** As for boulder reef projects, other habitat types will go to the same process of site selection, recommendations for best practice and follow-up monitoring to assess project success and ecosystem services provided. **Project phases.** Based on experience from various projects, a boulder project includes definition of purpose, a site selection process containing: Historic occurrence, environmental conditions, associated nature values (connectivity) and protection measures and recommendations for best practice and follow-up monitoring to assess project success and ecosystem services provided.
Read more	Detailed guidelines can be found here: • https://www.danishmarinerestoration.com/media/72639/stenrev-best-practice.pdf • https://www.danishmarinerestoration.com/media/72650/biogenic-reefs-site-selection-guideline-for-blue-mussel-bed-establishment.pdf • https://www.danishmarinerestoration.com/media/72782/guidelines-for-the-establishment-of-blue-mussel-beds-and-follow-up-monitoring.pdf • Flindt, M., Steinfurth, R., Banke, T.L., Lees, M.K., Svane, N., and Canal-Vergés, P. 2024. Human impacts, environmental disturbances, and restoration of seagrasses. Pages 512–548. In: D. Baird, M. Elliott (eds) *Treatise on estuarine and coastal science*. Amsterdam, Netherlands: Elsevier. https://doi.org/10.1016/B978-0-323-90798-9.00119-0

7.7.7 Coastline Protection and Seascape Restoration in Denmark

<table>
<tr><td>Project</td><td>COASTal LIFE</td></tr>
<tr><td>By</td><td>Jens Kjerulf Petersen DTU Aqua, Denmark</td></tr>
<tr><td>Feature</td><td>Bouder reefs, mussel banks, eelgrass, native oysters</td></tr>
<tr><td>Country</td><td>Denmark</td></tr>
<tr><td>Measures</td><td>

Description. The nearshore coastal environment is degraded in many ways like eutrophication, fisheries, stone extraction, land exclamation and climate change inducing sea level rise and coastal erosion. In the COASTal LIFE project, all of these pressures are addressed in a project aiming for bridging efforts across the shoreline

Project components. The project case study for Loegstoer Broad, Limfjorden includes recovery of salt meadows through changing drainage, flooding of lagoons and salt moors, (re)construction of islets/barrier islands, deployment of boulder reefs and beds of native oysters and blue mussels and eelgrass transplantation.

</td></tr>
<tr><td>Read more</td><td>https://www.coastal-life.dk/en/</td></tr>
</table>

7.7.8 Native Oyster and Horse Mussel Restoration in Denmark

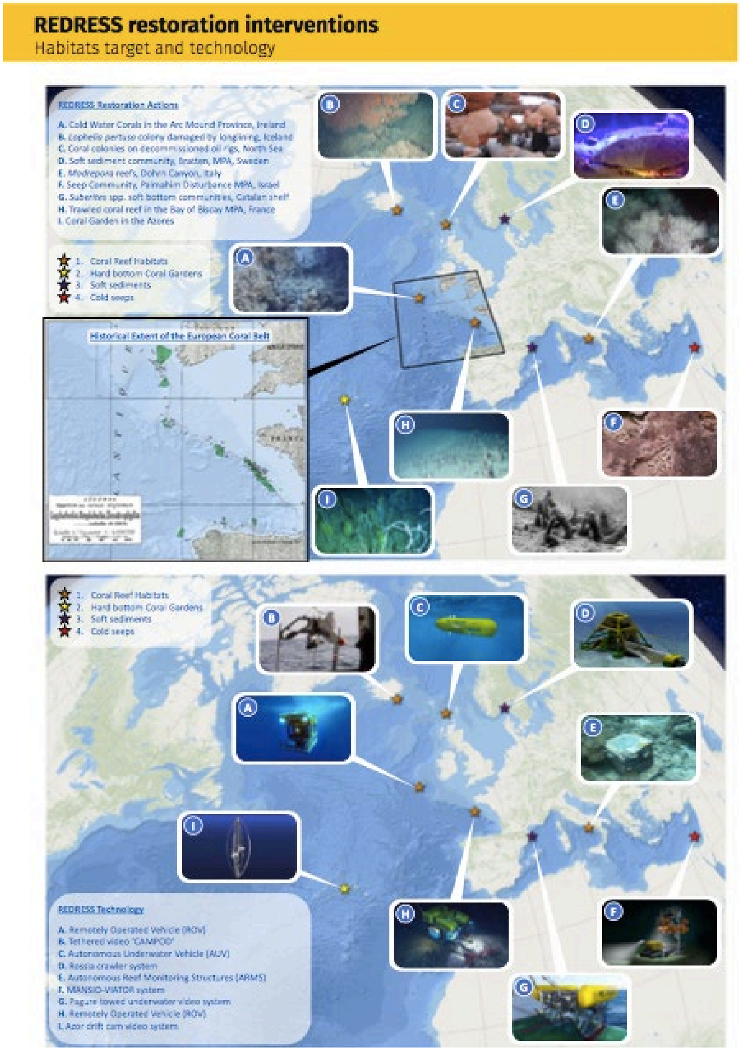
Project	BioReef
By	Jens Kjerulf Petersen DTU Aqua, Denmark
Feature	Horse mussel (*Modiolus modiolus*), native oysters (*Ostrea edulis*)
Country	Denmark
Measures	**Description.** Native oyster and horse mussel beds are endangered and/or red list species requiring active nature restoration to recover lost valuable habitats providing several ecosystem services. **Project components.** There are 2 primary goals of the BioReef project: a) To establish 1-3 ha size shellfish beds of horse mussel and native oysters; b) To develop protocols and best practices for production of disease-free seeding material for the reefs incl. appropriate cultch, and methods of deployment securing survival of the established reefs.
Read more	BioReef - Restoring Biogenic Reefs - Center for Marin Naturgenopretning

7.7.9 Oyster Restoration in the Netherlands; NORA

Projects	Dutch North Sea Regeneration programme, NORA
By	Oscar Bos, Wageningen Marine Research, Netherlands
Feature	Native oysters (*Ostrea edulis*)
Country	Netherlands, Europe
Measures	In the Netherlands, a number of different offshore flat oyster restoration projects take place (Bos et al., 2023), with the aim of upscaling them in the near future. Until so far, funding was mostly private, but in the coming years the majority of measures will be funded by the governmental North Sea Regeneration Programme (150MEuro, 2023-2030).  The main challenges for oyster restoration are described in Zu Ermgassen et al. (2020). Insight in the historic distribution of European flat oyster reefs in Europe is given in Thurstan et al. (2024). An overview of all European oyster restoration projects is provided by the Native Oyster Restoration Alliance (NORA) (https://noraeurope.eu/). NORA has developed a series of concisely written and well-illustrated handbooks on project design and planning, site selection and monitoring methods (Zu Ermgassen et al., 2021) that could be useful as inspiration for other species groups. 
Read more	NORA: https://noraeurope.eu/ Bos, O. G., Duarte-Pedrosa, S., Didderen, K., Bergsma, J. H., Heye, S., & Kamermans, P. 2023. Performance of European oysters (Ostrea edulis L.) in the Dutch North Sea, across five restoration pilots. Frontiers in Marine Science, 10, Article 1233744. https://doi.org/10.3389/fmars.2023.1233744 Thurstan, R. H., McCormick, H., Preston, J., Ashton, E. C., Bennema, F. P., Cetinić, A. B., Brown, J. H., et al. 2024. Records reveal the vast historical extent of European oyster reef ecosystems. Nature Sustainability. https://doi.org/10.1038/s41893-024-01441-4 zu Ermgassen, P. S. E., Bonačić, K., Boudry, P., Bromley, C. A., Cameron, T. C., Colsoul, B., Coolen, J. W. P., et al. 2020. Forty questions of importance to the policy and practice of native oyster reef restoration in Europe. Aquatic Conservation: Marine and Freshwater Ecosystems, 30(11), 2038–2049. https://doi.org/10.1002/aqc.3462 zu Ermgassen, P., Bos, O., Debney, A., Gamble, C., Glover, A., Pogoda, B., Pouvreau, S., et al. 2021. *European native oyster habitat restoration monitoring handbook November 2021*. The Zoological Society of London, UK., London, UK. https://noraeurope.eu/wp-content/uploads/other-publications/European-Native-Oyster-Habitat-Restoration-Monitoring-Handbook.pdf

7.7.10 Deep-sea Habitats in Europe

Project	REDRESS: Restoration of deep-sea habitats to rebuild European Seas
By	Chris Smith and Nadia Papadopoulou, Greece
Feature	Cold water corals, coral and sponge gardens, soft sediments and chemosynthetic seeps
Countries	North East Atlantic (Iceland, UK, Ireland, France, Portugal, Sweden) and Mediterranean (Spain, France, Italy, Israel)
Measures	The follow up of MERCES EU project is the REDRESS Project for the North East Atlantic and the Mediterranean Sea basin The REDRESS Innovation Action project is funded under the Horizon Europe programme (Project number: 101135492) under "Biodiversity and ecosystem services". It runs for 4 years from February 2024 and has a grant of 8.5 mEuro). The project targets the deep sea with restoration of 11 deep water sites (200-1100 m) in the North East Atlantic (Iceland, UK, Ireland, France, Portugal, Sweden) and Mediterranean (Spain, France, Italy, Israel) The target habitats are cold water corals, coral and sponge gardens, soft sediments and chemosynthetic seeps. Restoration actions are both passive including recovery of protected areas, and various interventions for active restoration ranging from deployment of artificial reefs (Ecoreef 3D printed or poured concrete) and metal frames, with or without coral transplants, and biorelease of invertebrate species returned from fisheries bycatch (gorgonian corals, sponges, seapens, holothurians and crustaceans) to coral gardens and soft bottoms. The project will also have industry involvement, with corals harvested from oil and gas platforms and fisheries bycatch from commercial fishing vessels.



Both MERCES and REDRESS have worked/are working on methods for active cold-water coral restoration including transplantation techniques and the utilization of artificial structures (Montseny et al., 2021). Transplantation involves the attachment of shallow water corals cold-water coral fragments to either natural or artificial substrates. Meanwhile, artificial structures, such as offshore oil and gas platforms, serve as sites for the larval recruitment of cold-water corals (Montseny et al., 2019, 2021; Edery et al., 2025; Villechanoux et al., 2022). REDRESS has also been working on advance monitoring techniques and innovative technologies to support upscaling marine restoration (Aguzzi et al., 2024).

Read more

REDRESS: https://redress-project.eu/

Aguzzi, J., Thomsen, L., Flögel, S., Robinson, N. J., Picardi, G., Chatzievangelou, D., Bahamon, N., et al. 2024. New Technologies for Monitoring and Upscaling Marine Ecosystem Restoration in Deep-Sea Environments, Engineering, 34: 195-211, https://doi.org/10.1016/j.eng.2023.10.012.

Edery, G., Viladrich, N., Garí, A., Montseny, M., Montero-Serra, I., Gori, A. and Linares, C. 2025. Sexual reproduction of actively restored gorgonians. Restor Ecol, 33: e14339. https://doi.org/10.1111/rec.14339

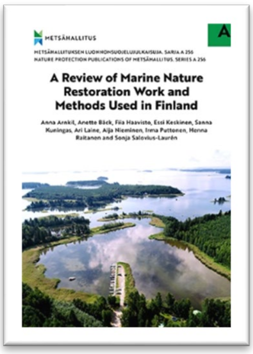
	Montseny, M., Linares, C., Carreiro-Silva, M., Henry, L.-A., Billett, D., Cordes, E.E., Smith, C.J., et al. 2021. Active Ecological Restoration of Cold-Water Corals: Techniques, Challenges, Costs and Future Directions. Front. Mar. Sci. 8:621151. doi: 10.3389/fmars.2021.621151 Montseny, M., Linares, C., Viladrich, N., Olariaga, A., Carreras, M., Palomeras, N., Gracias, N., et al. 2019. First attempts towards the restoration of gorgonian populations on the Mediterranean continental shelf. *Aquatic* Conserv: Mar Freshw Ecosyst. 2019; 29: 1278–1284. https://doi.org/10.1002/aqc.3118 Villechanoux, J., Bierwirth, J., Mantas, T. P., and Cerrano, C. 2022. Testing Transplantation Techniques for the Red Coral *Corallium rubrum*. Water, 14(7), 1071. https://doi.org/10.3390/w14071071

7.7.11 Process of Forming a Restoration Action Plan

Project	Development of a Scottish Marine and Coastal Restoration plan: strategic approach to restoration
Feature	Restoration of marine and coastal habitats and species (e.g. seagrass, flat oyster beds (*Ostrea edulis*) and saltmarshes)
By	Elena Balestri. Scottish Fishermen's Federation. Member of the Scottish Marine and Coastal Restoration Plan - Advisory Group
Country	Scotland
Measures	In UK, the devolution of conservation policies translates into a slightly different approach taken in Scotland when compared to the rest of the country. The Scottish Biodiversity Strategy was published in 2024. The ambitions and targets of this strategy will be delivered via a series of multiannual action plans the first of which will cover the period between 2024 and 2030. One of the targets of the strategy is to have a Marine and Coastal Restoration Action Plan in place by the end of 2025. As a result, Scottish Government Marine Directorate are leading work to develop the plan and, to implement a more inclusive approach, have established a Stakeholder Advisory Group that will help in the creation and reality check of the plan. The work of the group, currently ongoing, is concentrating on four main topics: Opportunity mapping and prioritisation, Finance and funding, Regulatory Environment and Supply chain and enabling drivers. The topics considered by the group touched upon: • identifying areas potentially suitable for restoration (based on use of modelled data for a range of environmental factors enabling exclusion of areas with biological or physical conditions not suitable for a specific species/habitat) – these are intended as a tool to support active restoration, recognising the need for validation at a regional/local level, • the regulatory framework to enable active restoration projects and to consider options for appropriate protection mechanisms for active restoration projects, including while they are happening and in future if successful,

	the potential way of funding these initiatives (public money, blend private/public funds, marketing of the initiatives, and, • the barriers for success (including failure of suitability and success modelling due to natural environment and limit of the supply chain). At this stage, the restoration plan will focus on active restoration, with pressure removal being considered only so far as it relates to the success of active restoration projects. Given the range of wider marine nature enhancement measures already under development in Scotland (such as the implementation of fisheries management measures within MPAs and the protection of priority marine features with the Scottish MPA network), there is recognition that focusing the plan mainly on active restoration will add value rather than duplicating existing effort. No reference point "to restore to" has been identified as the plan is forward looking and focuses on enhancing the marine environment and contributing to the achievement of the wider conservation targets, including halting and reversing the trend of biodiversity loss and becoming Nature Positive. This more strategic and coordinated approach follows proposals by the Scottish Government in 2024 which would have allowed projects to carry out a self-assessment of environmental impacts under a registration process. The view of some respondents to a consultation on these proposals was that this would have favoured an easier but scattered approach. The belief is that a more strategic approach to restoration has the potential of maximizing the chance of success of scientifically sound projects, streamlining the need for funding, and maximising potential socio-economic benefits while minimising negative socio-economic impacts.

7.7.12 Ongoing Active Restoration Within Biodiversea Life IP Project in Finland

Project	Biodiversea Life IP
By	Lasse Kurvinen Metsähallitus Parks & Wildlife Finland, Sanna Kuningas Natural Resources Institute Finland
Feature	Seagrass (*Zostera marina*), Mossy stonewort (*Chara tomentosa*), bladderwrack *(Fucus vesiculosus);* lagoons, estuaries, fish, birds
Country	Finland
Measures	The EU co-funded Biodiversea Life IP project is running from 2021-2029, with a total budget of around 20 million euros. A significant part of the project is related to restoration, either by piloting methods or upscaling exciting methods.  **Coastal lagoons**: Measures include mainly restoring dredged thresholds or opening of the channel, which has been impeded due to human activities. The aim of restoration often aimed towards supporting fish spawning or increasing the state of the lagoon. **Keystone species**: Reintroducing species, such as *Zostera marina, Chara tomentosa* or *Fucus vesiculosus* to areas, from where they have disappeared. Some of these have already been tested, but e.g. *Fucus* related actions are still under development **Estuaries**: Reforming the modified deltas towards a more natural state. **Breeding birds**: Eradication of alien predators, such as Racoon Dog and American Mink The project is also developing a practical plan on prioritizing restoration sites.
Read more	Arnkil, A., Bäck, A., Haavisto, F., Keskinen, E., Kuningas, S., Laine, A., Nieminen, A., et al. 2024. A Review of Marine Nature Restoration Work and Methods Used in Finland. NATURE PROTECTION PUBLICATIONS OF METSÄHALLITUS. SERIES A 256 (https://julkaisut.metsa.fi/en/publication/a-review-of-marine-nature-restoration-work-and-methods-used-in-finland/)

7.7.13 Reoxygenation of Low Oxic Coastal Marine Environments

Project	Baltic Sea Oxygenation and the Super-Green Hydrogen Economy (BOxHy)
By	Patricia Handmann, Lhyfe, France
Feature	Marine reoxygenation
Country	France (demonstration in Baltic Sea and Gulf of St. Lawrence)
Measures	The BSAP-funded BOxHy project, endorsed by the United Nations Decade of Ocean Science for Sustainable Development (10/2023 – 10/2024), aims to develop a marine reoxygenation demonstrator using scalable linear diffuser technology from the freshwater restoration sector (Cooke et al., 2005). The project explores how oxygen by-products from offshore renewable hydrogen production can help manage nutrient reserves and address anoxia and hypoxia to restore ecosystem health. A methodology for site selection, cost estimation, and demonstrator duration has been established. Currently, the team is working on two potential demonstrators: one in the Baltic Sea and another in the Gulf of St. Lawrence.
Read more	BOxHy Project: Lhyfe Moves Towards Ocean Reoxygenation - H2Today Cooke, G. D., Welch, E. B., Peterson, S., and Nichols, S. A. 2016. Restoration and management of lakes and reservoirs. CRC press. Flexens, Stockholm University and Lhyfe, Baltic Sea Oxygenation and the Super-Green Hydrogen Economy 2024, https://flexens.com/wp-content/uploads/2024/11/BOxHy_Report_FINAL_2024.pdf

7.7.14 LIFE – RESTORESEAGRASS in Portugal

Project	LIFE – RESTORESEAGRASS
By	Nuno Oliviera, Porugal
Feature	Seagrass habitat, target species include *Zoostera marina*, *Z. noltei*, *Ruppia* spp., etc.
Country	Portugal (Ria Formosa, coastal lagoon complex in Algarve)
Measures	The project aims to secure a network of healthy seagrass habitats present along the coast of Portugal Mainland and Iberian Peninsula. The selected sites are important historic or recent seagrass beds. In Arrábida, restoration started 2 decades ago. The lessons learn are now planned to be replicated in Ria Formosa coastal lagoon. Measures include: • Planting seagrass in areas where the species disappeared due to humane activities; • Cultivation of rare declining seagrass species integrated in fish farms with manipulated conditions that have been tested for a proof of concept of effectiveness; • Remove invasive algal species.

	• Develop the first seagrass restoration demonstration nature park, integrating activities of birdwatching to attract volunteers to participate in seagrass restoration.
Read more	Paulo, D., Cunha, A. H., Boavida, J., Serrão, E. A., Gonçalves, E. J., and Fonseca, M. 2019. Open coast seagrass restoration. Can we do it? Large scale seagrass transplants. Frontiers in Marine Science, 6, 52. Paulo, D., Diekmann, O., Ramos, A. A., Alberto, F., and Serrão, E. A. 2019. Sexual reproduction vs. clonal propagation in the recovery of a seagrass meadow after an extreme weather event. Scientia Marina, 83(4), 357-363. Greiner, J.T., McGlathery, K.J., Gunnell, J., McKee, B.A. 2013. Seagrass Restoration Enhances "Blue Carbon" Sequestration in Coastal Waters. PLoS ONE 8(8): e72469.doi:10.1371/journal.pone.0072469 Marbà, N., Arias-Ortiz, A., Masqué, P., Kendrick, G.A., Mazarrasa, I., Bastyan, G.R., Garcia-Orellana, J. et al. 2015. Impact of seagrass loss and subsequent revegetation on carbon sequestration and stocks. Journal of Ecology, 103 (2): 296–302. doi: 10.1111/1365-2745.12370. Blandon, A., and zu Ermgassen, P.S.E. 2014a. Quantitative estimate of commercial fish enhancement by seagrass habitat in southern Australia. Estuar. Coast. Shelf Sci. 141, 1-8. doi.org/10.1016/j.ecss.2014.01.009. Blandon, A., and zu Ermgassen, P.S.E. 2014b. Corrigendum to "Quantitative estimate of commercial fish enhancement by seagrass habitat in southern Australia". Estuar. Coast. Shelf Sci. 151, 370. doi.org/10.1016/j.ecss.2014.10.006. zu Ermgassen, P.S.E., DeAngelis, B., Gair, J.R., zu Ermgassen, S., Baker, R., Daniels, A., MacDonald, T.C., et al. 2021. Estimating and Applying Fish and Invertebrate Density and Production Enhancement from Seagrass, Salt Marsh Edge, and Oyster Reef Nursery Habitats in the Gulf of Mexico. Estuaries Coast, doi.org/10.1007/s12237-021-00935-0 Jackson, E.L., Rees, S.E., Wilding, C., and Attrill, M.J. 2015. Use of a seagrass residency index to apportion commercial fishery landing values and recreation fisheries expenditure to seagrass habitat service. Conserv. Biol. 29, 899–909. DOI: 10.1111/cobi.12436 Jänes, H., Macreadie, P.I., Zu Ermgassen, P.S.E, Gair, J.R., Treby, S., Reeves, S., Nicholson, E., et al. P. 2020. Quantifying fisheries enhancement from coastal vegetated ecosystems, Ecosyst. Serv., 43, doi.org/10.1016/j.ecoser.2020.101105. Tuya, F., Haroun, R., and Espino, F. 2014. Economic assessment of ecosystem services: monetary value of seagrass meadows for coastal fisheries. Ocean Coast. Manage. 96, 181–187. doi.org/10.1016/j.ocecoaman.2014.04.032.

8 Harnessing ICES Expertise

This section corresponds to WKREST ToR d) Report on the ways in which existing data streams/ calls and methods adopted by the ICES Data Center and expert groups may contribute to meeting evidence needs and priorities identified in ToR a-d.

Key Messages

- **Further development and enhancement of expertise within the ICES network** of active restoration (especially for offshore areas) projects, further knowledge required of recovery rates for species and habitat types, and better direct detection/ measurement of recovery rates, and ecological connectivity.
- **Need to further improve the coordination, accessibility and integration benthic data sets**, this is especially relevant for benthic invertebrate data collected by the IBTS surveys, and also data sets generated by international research projects, industry and national monitoring and assessment programmes.
- **Continue to further develop ICES databases, data visualization and QA/ QC tools:** to enhance access to EG data and knowledge for improved ecosystem science and the provision of robust management advice.

8.1 ICES Data Calls

Data driven analysis and knowledge synthesis are central to ICES scientific based advice, and data calls are an important part of that process. Given their importance to ICES advisory work, ICES has produced a set of guidelines to help explain the processes and criteria for the two types of data call that ICES requests (ICES, 2025b); namely: (i) data calls which are issued directly by ICES; these tend to be associated with recurring advice requests, special requests, and are issued by the ICES Secretariat with hard deadlines that are enforced; examples include commercial catch data, VME data, VMS and logbook data; (ii) data calls issued by ICES expert groups; these tend not to support advice requests and are issued by expert group members directly, examples include ocean climate data (Working Group on Oceanic Hydrography, WGOH).

8.1.1 VME Data Call

Each year, ICES issues a 'Call for data: new information on Vulnerable Marine Ecosystems (VME) in the North Atlantic from ICES member countries'. This is sent to all member countries via DCF national correspondents and ACOM members. The call requests data from both old and new data sources, as well as absence records. A list of deep-water VMEs and their characteristic taxa is provided in the call, based on FAO criteria (FAO, 2009) and refinements by the Joint ICES/NAFO Working Group on Deepwater Ecology (WGDEC). At each data call, member countries are also encouraged to make resubmissions to update VME data previously submitted to ICES, if necessary. Resubmissions overwrite earlier versions of the data. ICES encourages, but cannot prescribe, effective collection and management of data within member countries. The **national recipients of the data call** are responsible for co-ordinating data submission, and close interaction with WGDEC members is encouraged given their experience working with VME data. Further quality assurance of submitted national data is conducted by the ICES Data Centre via the Data Screening Utility (DATSU) tool. This runs a series of automated checks to ensure entries on the template are logical and internally consistent. Any identified errors are addressed with the national data provider. Once these checks are complete the data are also examined by WGDEC before being upload to the database, and WGDEC will also conduct further reviews of the data during their work. Any issues arising are raised with national data providers and national review and resubmission is requested if errors are identified. The flow of data into the VME database and data portal is published as a Data Flow Schematic (ICES, 2024a).

8.1.2 VMS Data and Data Call

The benchmarked method for providing VME advice (as defined in Annex 6 of the Benchmark Workshop on the occurrence and protection of VMEs; ICES, 2022) also requires VMS data. VMS data, coupled with logbook data from vessels, are used to describe the spatial dynamics of bottom fishing activities. The data call for VMS data is sent annually to all member countries via Data Collection Framework national correspondents and ACOM members. The call requests VMS and coupled logbook data that are anonymized and aggregated by month in 0.05° x 0.05° c-squares (2024 call: VMS data call[11]).

A range of tools are provided by ICES to support and enable data submission under this call, and ICES Data Centre conducts quality checks using standardized tools that create summary variables and maps to compare recent values with previous submissions. A report generated as part of the quality checks is reviewed by the ICES Working Group on Spatial Fisheries Data (WGSFD) and any quality issues are addressed with the national data providers. The submitted data are maintained in a secure database, and are processed into data products before use and publication. The data flow into the ICES data management systems are published as a Data Flow Schematic for the northeast Atlantic (ICES, 2021) and the NEAFC Regulatory Areas (ICES, 2020b).

Processed VMS data are considered 'sensitive' if activities of individual vessels can be inferred from the data. To preserve vessel anonymity in the aggregated VMS data, any data for 0.05° x 0.05° c-squares with records for two vessels or less is only presented in the form of ranges. The benchmarked method for providing VME advice uses the VMS data and information on dimensions of mobile bottom contact gears to estimate Swept Area Ratio (SAR). SAR is the total area swept by a given gear over a defined time period (usually 1 year) in the 0.05° x 0.05° c-square divided by the area of the 0.05° x 0.05° c-square. Swept area is calculated as the product of fishing time (inferred from ping interval), towing speed, and dimensions of gear components contacting the seabed summed over the different types of mobile bottom contacting gear in use. Values of SAR by c-square do not allow individual vessels to be identified, and so SAR values are used and reported in VME advice even if there are two or fewer vessels recorded in the c-square. In the benchmarked method for providing VME advice (ICES, 2022), a SAR value of ≥0.43 is assumed to distinguish 0.05° x 0.05° c-squares in which the risk of further significant adverse impacts on VME from mobile bottom contacting gear is considered low (ICES, 2022) on account of the probability of finding any intact/ live VME at or above this level of fishing effort is low. Significant adverse impacts (SAI) are those that compromise ecosystem integrity (i.e. ecosystem structure or function) as described in the FAO International Guidelines for the Management of

[11] https://ices-library.figshare.com/articles/report/ICES_Data_call_2024_-_Data_submission_of_VMS_Log_book_data/25846339?file=46387369 Accessed 2.21.2025.

Deep-sea Fisheries in the High Seas (FAO, 2009). In the 2023 advice (ICES, 2023a), average SAR values are calculated using VMS data from 2009–2021.

Beginning with the 2024 VMS data call, fields were added requesting the inclusion of the MSFD Broad Habitat type and 200m bathymetry intervals. In relation to bathymetry, VMS pings are assigned to a value from A – I to correspond to the 200m isobath polygons (as developed for the NEAFC depth of fishing special request: NEAFC depth of fishing, polygons created from a contoured version of the GEBCO 15 arcsecond grid (2022), in 200 m bins from 0 m to 1400 m), before aggregating to c-squares (ICES, 2023b). This will permit assessment of fishing activity in relation to depth within c-squares that span broad depth ranges.

8.2 ICES Data Centre (Databases and Tools)

The ICES Data Centre plays a crucial role in managing and providing access to a wide range of marine data, essential for supporting marine science and policy. This is achieved through coordinating data collection from various sources, including member countries, research institutes and monitoring programmes and ensuring high quality data provision through implementing standardised methods, quality checks and data validation processes (ICES-best-practice-data-management). In addition, data storage in well-organised databases (notably; DATRAS, VME and DOME – see below) enables the data holdings to be easily accessible for analysis and research purposes. The following database descriptions are those which are most relevant to studies of nature restoration and recovery.

8.2.1 DATRAS (Database of Trawl Surveys)

DATRAS is an online database that collates and documents data from bottom trawl fish surveys, including data from the International Bottom Trawl Surveys (IBTS). It ensures data quality, standardised data formats and facilitates data handling and availability. The database includes data from the Baltic Sea, Skagerrak, Kattegat, North Sea, English Channel, Celtic Sea, Irish Sea, Bay of Biscay, and the eastern Atlantic from the Shetlands to Gibraltar (DATRAS). It includes data on catch per unit effort (CPUE), biological information and swept area trawl information which are sued to inform stock assessments and fish community studies. Of particular relevance to studies of habitat restoration and recovery are the data collected as part of the International Bottom Trawl Surveys coordinated by the International Bottom Trawl Survey Working Group (IBTSWG) which includes parameters associated with benthic habitats and macro invertebrate communities (see below for further details). Data products and raw data from DATRAS can be freely downloaded according to the ICES data policy.

8.2.2 DOME (Database on the Marine Environment)

The purpose of DOME is to manage important chemical and biological data sets for regional marine assessments undertaken by OSPAR, HELCOM and AMAP (DOME). The database includes monitoring data on a broad range of chemical parameters (e.g., metals, PAHs, brominated flame retardants) and biological data (e.g., histopathology, ocean acidification, benthos and plankton) used for biological effects temporal and spatial trend analysis. Data are reported according to specific guidelines and are available through the DOME portal (https://www.ices.dk/data/data-portals/Pages/DOME.aspx).

8.2.3 ICES VME Database

ICES collates and makes available evidence on the distributions and types of Vulnerable Marine Ecosystems (VMEs) in the North Atlantic (including areas within and outside national jurisdiction) in the ICES VME database (https://www.ices.dk/data/data-portals/Pages/vulnerable-marine-ecosystems.aspx). The purpose of this database is to support scientific research into VME and their interactions with people and the environment, and to provide inputs to the analyses that underpin ICES advice. Records come from a variety of sources, ranging from dedicated research cruises that photograph and characterise VME with high-resolution seabed imaging systems, to fishing trawl and longline bycatch records. Records in the database comprise 'VME habitats' that are records for which there is unequivocal evidence for a VME (e.g., from direct observation), 'VME indicators' which are records that suggest the presence of a VME with varying degrees of uncertainty, and 'VME absence'. New and updated records are submitted to the database by ICES Member Countries following an annual data call and reviewed annually by The Joint ICES/NAFO Working Group on Deep-water Ecology (WGDEC). The ICES VME Webservice provides the ability to display VME data contained within the database on a Geographical Information System (GIS).

8.3 Network of ICES Expert Groups

There are over 170 Expert Groups (EGs) in the ICES science network whose activities are overseen by eight Steering Groups (i.e., aquaculture; data science and technology (DSTSG); ecosystem observations (EOSG); ecosystem processes and dynamics (EPDSG); fisheries resources (FRSG); human activities, pressures and impacts (HAPSIG); human dimension (HUDISG); and ecosystem approaches and methods (EAMSG) under the Science Committee, SCICOM). The steering groups and their expert groups play a vital role in advancing marine science in ICES and ensuring the sustainable management of marine resources is achieved by addressing the strategic science priorities identified in the ICES Science Plan (ICES, 2025c).

A search for the word "restoration" in the ToRs of all ICES EGs identified six working groups apparently undertaking investigations relevant to nature restoration and recovery science (i.e., the Working Group on Science to Support Conservation, Restoration and Management of Diadromous Species (WGDIAD), Benthos Ecology Working Group (BEWG), Working Group on Marine Mammal Ecology (WGMME), Working Group on the Value of Coastal Habitats for Exploited Species (WGVHES), Working Group on Offshore Wind Development and Fisheries (WGOWDF) and Working Group Marine Planning and Coastal Zone Management (WGMPCZM)). However, not all expert groups, known to be working with datasets and undertaking assessments relevant to nature restoration and recovery, have specific ToRs which highlight 'restoration'. Therefore, SG Chairs were approached to identify expert groups they considered to be working with data and undertaking relevant assessments. The results of this consultation, including the identification of ICES expert groups using the term 'restoration', resulted in 19 expert groups that have the potential to directly contribute to assessments of nature restoration and recovery. Details of these groups are summarised in Table 8.1.

The identified expert groups generally fall into one of four categories with respect to their potential links and contributions to studies of nature restoration and recovery, namely; (i) expert groups which either directly obtain relevant monitoring data, or coordinate relevant marine monitoring programmes, that are operationally uploaded to ICES databases, e.g., on benthic habitats, species and oceanographic parameters (WGDEC, IBTSWG, WGOH); (ii) expert groups which routinely develop assessment tools and produce data products using monitoring programme data, such as mapping human activities, modelling habitat and species distributions and impacts linked to management advice (WGSFD, Working Group on Marine Habitat Mapping (WGMHM), WGMME, Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT), Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem (WGEXT)); (iii) expert groups which generate data products (including policy reviews) and tools (e.g., databases) from reviews of published literature and national case studies on habitat restoration (WGDIAD, WGVHES, WGMPCZM, Workshop to scope for Harmonized

Regional Monitoring Schemes to Assess the Impact of Offshore Wind Farms on Fish, Pelagic and Benthic Communities and Ecosystem Functions (WKOMO)), and (iv) expert groups which conduct ad hoc investigations directly relevant to habitat restoration and recovery through links with relevant national and EU monitoring and assessment research projects and monitoring programmes, some of which also support management advice (BEWG, Working Group on North Atlantic Salmon (WGNAS), Working Group to Develop and Test Assessment Methods for Sea Trout Populations (anadromous *Salmo trutta*) (WGTRUTTA), Assessment Working Group on Baltic Salmon and Trout (WGBAST), Working Group on Marine Protected Areas and other Spatial Conservation Measures (WGMPAS), Working Group on Offshore Wind Development and Fisheries (WGOWDF), Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED)).

Currently, there are requests to share IBTSWG benthic invertebrate data with the Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT; all epi-benthic species) and the Working Group on Deepwater Ecology (WGDEC; specifically for sea pens such as *Pennatula*). These data, however, are not always available on DATRAS or described in a satisfactory manner. It would potentially be useful to summarize the observations made for all the IBTS surveys, including the temporal coverage and to propose an annual evaluation of the quality of these data (standard protocol, complete or partial observation, skills on board ...). The question of systematically loading these data to DATRAS, or subsets of these data (e.g., the more robust, quality-assured data), also requires future discussions. In general, a better exchange concerning the protocols or the identification guides for benthic invertebrates would also allow a better harmonization of these data and integration with existing databases – e.g., the VME database.

The BEWG members are also participants of the EU EmodNET biology consortium, therefore keeping up to date with current and relevant international data series initiatives.

Table 8.1. Identified ICES Expert Groups which either directly investigate issues related to nature restoration and recovery, or have the potential to contribute to restoration science and advice.

Working Group (type)	Steering Group.	Data routinely accessed/ used, e.g. data streams or data calls.	Assessment methods being developed and/or adopted.	Relevant WG Reports and sources of information.	'Key' Contacts (email)
WGDEC[12]	HAPISG	Annual VME data call to ICES member countries.	VME Index. Distribution of different types of VME habitats and assessment of their sensitivity and resilience to bottom fishing activities.	Final report in 2024 of the ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC).	David Stirling (David.Stirling@gov.scot)
WGFBIT[13]	HAPISG	Benthic invertebrate data sets from national monitoring programmes and EU R&D projects, including species biomass/ abundance, biological traits and functions.	Soft sediment habitat recovery rates using population dynamic models, following bottom trawling disturbance.	Final report in 2023 of the Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT).	Jan Hiddink (j.hiddink@bangor.ac.uk), Marija Sciberras (m.sciberras@hw.ac.uk)
WGDIAD[14]	FRSG	Synthesize evidence of restoration success and failure and share knowledge on how restoration can be better integrated into assessment work.	Undertakes reviews and synthesizes habitat restoration practices to support ICES advice. Iintegrates of diadromous fish data into ICES databases	Specifically WGDIAD ToR B; and report of the Working Group on Science to Support Conservation, Restoration and Management of Diadromous Species (WGDIAD)	Jenni Prokkola (jenni.prokkola@luke.fi)
WGNAS[15]	FRSG	National salmon catches and abundance estimates around the North Atlantic, as inputs to oceanic-scale life cycle model, provided through ICES data call; Numbers of stocks assessed against BRPs, their status and trends re decline and recovery	Oceanic and continental scale stock assessments in support of ICES Advice on fishing opportunities to NASCO, Life Cycle Model	Final report in 2024 of the Working Group on North Atlantic Salmon (WGNAS) NASCO Strategic Objectives The Future of NASCO - a Ten-Year Strategy - NASCO	Alan Walker (alan.walker@cefas.gov.uk)

[12] Expert groups which either directly obtain relevant monitoring data, or coordinate relevant marine monitoring programmes.

[13] Expert groups which routinely develop assessment tools and produce data products using monitoring programme data.

[14] Expert groups which generate data products (including policy reviews) and tools (e.g. databases) from reviews of published literature.

[15] Expert groups which conduct *ad hoc* investigations directly relevant to habitat restoration and recovery.

Working Group (type)	Steering Group.	Data routinely accessed/ used, e.g. data streams or data calls.	Assessment methods being developed and/or adopted.	Relevant WG Reports and sources of information.	'Key' Contacts (email)
WGTRUTTA[(4)]	FRSG	National trout abundance, river habitat inventories, atlas of in-river barriers to migrations	GIS related tools to visualize sea trout distributions, those of environmental drivers and anthropogenic pressures, working with ICES Data Centre;	Final report in 2024 of the Working Group to Develop and Test Assessment Methods for Sea Trout Populations (WGTRUTTA), plus training and knowledge exchange on habitat restoration.	Alan Walker (alan.walker@cefas.gov.uk); Johan Höjesjö (johan.hojesjo@bioenv.gu.se)
WGBAST[(4)]	FRSG	National salmon and trout catches and abundance estimates around the Baltic Sea, as inputs to a full life-history model (for salmon) and for trends in juvenile recruitment status (for trout).	Stock assessments in support of ICES Advice on fishing opportunities for salmon (annual) and for trout (every second year)	Final report in 2024 of the Baltic Salmon and Trout Assessment Working Group (WGBAST).	Katarina Magnusson (katarina.magnusson@slu.se) Katarzyna (Kate) Nadolna-Ałtyn (knadolna@mir.gdynia.pl)
IBTSWG[(1)]	EOSG	Observations of the benthic organisms caught in the survey trawls are carried out on numerous IBTS-coordinated surveys. These series of data are of interest because of their sampling with similar gear and the relatively wide geographical coverage.	ICES' International Bottom Trawl Survey Working Group (IBTSWG) has its origins in the North Sea (Subarea 4), and the Skagerrak and Kattegat (Division 3.a), where coordinated surveys have occurred since 1965. Coordinated surveys in the North Sea are currently conducted in Q1 (NS-IBTS-Q1) and Q3 (NS-IBTS-Q3), and these provide the best time-series data for a range of fish stock and ecosystem related parameters, including stomach contents analysis and records of benthic invertebrates.	Final report in 2024 of the International Bottom Trawl Survey Working Group (IBTSWG).	Patrik Börjesson, David Stokes
WGMHM[(2)]	HAPISG	Data from national monitoring programmes and EU R&D projects specific to benthic communities to support SDM developments.	Development and application of predictive habitat suitability models to help identify and inform the recovery potential of different habitat types.	Final report in 2024 of the Working Group on Marine Habitat Mapping (WGMHM).	Julian Burgos, (julian.burgos@hafogvatn.is), Jose Manuel Gonzalez Irusta
WGMPAS[(4)]	HAPISG	Data from national monitoring programmes and EU R&D projects	The group are developing methods to assess the biodiversity of MPAs, including strictly protected areas to assess passive biodiversity recovery potential for different types of habitats.	WG poster in 2023. Marine Protected Areas and other Spatial Conservation Measures (WGMPAS)	Emma Sheehan (emma.sheehan@plymouth.ac.uk), Joachim Claudet (joachim.claudet@gmail.com), Ryan Stanley (ryan.Stanley@dfo-mpo.gc.ca)

Working Group (type)	Steering Group.	Data routinely accessed/ used, e.g. data streams or data calls.	Assessment methods being developed and/or adopted.	Relevant WG Reports and sources of information.	'Key' Contacts (email)
BEWG[4]	EPDSG	The Benthos Ecology Working Group (BEWG) aims to study, describe and update on all aspects relevant to the ecology, functioning and interactions of marine benthic species (living in or within the sediment), either macro-, meio- and epifauna across the Northeastern Atlantic. A series of benthic, biological traits and sediment data sets has been compiled and is regularly up-dated and used by the group.	Assessments of "changes in functional composition along sediment gradients" and "the role of benthos within MPAs".	Specifically BEWG ToR E and the final report in of the Benthos Ecology Working Group (BEWG)	Johan Craeymeersch (Johan.Craeymeersch@wur.nl), Paolo Magni (paolo.magni@cnr.it).
WGVHES[3]	HAPISG	Extensive literature review on methods for assessing Habitat Quality of Juvenile Fish in Coastal Environments. A total of 996 papers were reviewed and their features entered into a universal Access database. Features include basic information on location, species, spatial and temporal scales, and what metrics and measures were used to quantify habitat quality based on abundance, growth, survival, and juvenile-to-adult linkage.	The Working Group on the Value of Coastal Habitats for Exploited Species (WGVHES) aims to assess and quantify habitat value for fisheries management including developing methods to assess the nursery habitat concept of exploited species.	Specifically WGVHES ToR C and the final report in of the Working Group on the value of Coastal Habitats for Exploited Species (WGVHES) Champagnat et al. 2021. Multidisciplinary assessment of nearshore nursery habitat restoration for an exploited population of marine fish. Mar Ecol Prog Ser 680:97-109. https://doi.org/10.3354/meps13881	Rochelle Seitz (seitz@vims.edu), Karen van de Wolfshaar (karen.vandewolfshaar@wur.nl)
WGMME[2]	EPDSG	Information on the abundance, distribution, and population/stock structure on cetacean and seal populations, including a seal database.	Investigating marine mammal indicators and targets for MSFD and implications for the EU 'restoration' law.	Specifically WGMME ToR B, and the final report in 2024 of the Working Group on Marine Mammal Ecology (WGMME)	Sophie Brasseur (Sophie.Brasseur@wur.nl); Peter Evans (oss61a@bangor.ac.uk)
WGOWDF[4] (closely linked to WKOMO)	HAPISG	Review tools and available data to measure and address effects and impacts of fisheries, conservation, and wind energy interactions on fisheries independent and dependent data collections.	Considering habitat restoration opportunities with respect to offshore renewable energy developments, notably fixed offshore windfarms.	Specifically WGOWDF ToR D, and the final report in 2024 of the Working Group on Offshore Wind Development and Fisheries (WGOWDF).	Andrew Lipsky (andrew.lipsky@noaa.gov); Andrew Gill (andrew.gill@cefas.co.uk); and Edward Willsteed (ed@howellmarine.co.uk)

Working Group (type)	Steering Group.	Data routinely accessed/ used, e.g. data streams or data calls.	Assessment methods being developed and/or adopted.	Relevant WG Reports and sources of information.	'Key' Contacts (email)
WKOMO[3] (closely linked to WGOWDF)	HAPISG	Inventory of operational and planned habitat/ environmental monitoring programmes and associated indicators to assess the impact assessment of offshore renewable energy developments.	Summary of research and monitoring activities in and around offshore wind areas by habitat type and regional sea to identify steps towards harmonised monitoring and research activities to assess the impacts of OREs and the effectiveness of mitigation measures, including passive habitat restoration opportunities.	Workshop on Harmonized Regional Monitoring Schemes to Assess the Impacts of Offshore Wind Farms on Fish, Pelagic and Benthic Communities and Ecosystem Functions (WKOMO).	Steven Degraer (steven.degraer@naturalsciences.be); and Vanessa Stelzenmüller (vanessa.stelzenmueller@thuenen.de)
WGMPCZM[3]	HUDISG	Conducted a review on national restoration plans and case studies.	Reported on the role of marine spatial planning (MSP) and coastal zone management (CZM) in facilitating marine and coastal ecosystem restoration.	Specifically WGMPCZM ToR B, and the final report in 2025 of the Working Group on Marine Planning and Coastal Zone Management (WGMPCZM).	Talya tenBrink (talya.tenbrink@uri.edu), Kira Gee (k.gee@gmx.de) and Malena Ripken (malena.ripken@uni-oldenburg.de)
WGSFD[2]	HAPISG	The Working Group on Spatial Fisheries Data (WGSFD) collates and analyses spatial fisheries data in order to evaluate fishing effort, intensity, and frequency in European waters. WGSFD coordinates an annual data call on VMS and log-book data.	Produced and analysed maps of fishing activity in EU waters (and NEAFC regulatory areas), using the VMS and catch information provided by the EU and NEAFC.	The final report in 2024 of the Working Group on Spatial Fisheries Data (WGSFD).	Jeppe Olsen (jepol@aqua.dtu.dk), Patrik Jonsson (patrik.jonsson@slu.se)
WGOH[1]	EPDSG	The Working Group on Oceanic Hydrography (WGOH) closely monitors the ocean conditions in the ICES area by updating and reviewing results from standard hydrographic sections and stations.	The primary work product of the WG is its annual ICES Report on Ocean Climate (IROC), which provides expert analysis of time-series observations of ocean hydrography collected at longstanding stations throughout the North Atlantic.	The final report in 2021 of the Working Group on Oceanic Hydrography (WGOH).	Ricardo Sanchez Leal (rleal@ieo.es), Frédéric Cyr (frederic.cyr@mi.mun.ca)

Working Group (type)	Steering Group.	Data routinely accessed/ used, e.g. data streams or data calls.	Assessment methods being developed and/or adopted.	Relevant WG Reports and sources of information.	'Key' Contacts (email)
WGEXT[2]	HAPISG	WGEXT collates data on areas of active dredging for marine sand and gravels. It also collates information and data on the impacts and rates of benthic recolonisation post dredging activities.	The group's objective is to provide a summary of data on marine sediment extraction, marine resource and habitat mapping, changes to the legal regime, and research projects relevant to the assessment of environmental effects. WGEXT has been monitoring the rate of marine sediment extraction in the North Atlantic, including the Baltic and North Sea for almost 40 years. The group is developing a database and associated 'WGEXT Dredging Dashboard' to document current extractions by end use, leased areas and, where possible, the footprint of dredged areas.	The final report in 2024 of the Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem (WGEXT). Dashboard of marine aggregate data holdings and activities (WGEXT dredging dashboard)	Keith Cooper (keith.cooper@cefas.gov.uk)
WGMBRED[4]	HAPISG	Routinely collates data which is hosted by their 'CRITTERBASE' database that currently contains data from Belgium, the Netherlands, Germany and Denmark on wind farms, gas platforms consisting of 1969 samples collected during 92 expeditions with 710 benthic taxa.	In 2019–2021, the group discussed guidelines for data collection and methodologies and developed an integrated example dataset on benthos data of marine renewable energy devices.	The final report in 2021 of the Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED).	Jolien Buyse (jolien.Buyse@ilvo.vlaanderen.be), Ninon Mavraki (ninon.mavraki@wur.nl)

9 Priority science for countries to implement restoration

A number of knowledge gaps were identified through WKREST and those that were seen as science priorities were compiled (Table 9.1) into those achievable in the short-, medium- and long-term in order to improve the effectiveness of restoration initiatives.

Table 9.1. Science priorities identified by WKREST subgroups

Topic (group)	Short-term (<2 years)	Medium-term (2 – 5 years)	Long-term (>10 years)
Modelling, assessment and monitoring of recovery times	Clarify definitions of terms (goals and objectives) related to restoration and timeframes for achieving restoration outcomes. Develop and implement an adaptive spatial data framework as nested hierarchical grid, to accommodate different resolution data.	Development of habitat maps (at appropriate resolution), key to assess state and potential habitat/ species restoration. Improved mapping of pressures (good at activities – need to better link activities to pressure mapping) Establish appropriate reference conditions for a full range of habitats and species.	There is limited understanding of how the scale of restoration activities, as well as the interactions between different restoration interventions, affect the success of restoration outcomes.
Connectivity assessments	Understanding the connectivity dynamics including connectivity networks with multiple sites in a healthy condition and positive reproductive rates is vital for long term sustainable restoration success. Therefore, connectivity modelling should be undertaken as part of the site selection process. These models can also be used to evaluate colonization potential of distribution maps. Depending on the species new knowledge may need to be obtained. For issues of passive dispersal, particle tracking models can be run to capture the dispersal envelope and followed up with more precise information from genetics, tagging or other methods if required (see Medium Term priorities). This information can establish hypotheses of source/sink relationships which is critical information for restoration success, especially for passive restoration initiatives. Ocean model projections into the future project currents as well as temperature and salinity changes. Such information can be used to anticipate changes in connectivity pathways and environmental suitability in future and allow for informed monitoring plans to track observational with modelled data.	Considerable knowledge gaps exist to evaluate connectivity as species dispersal traits and migration routes for many species are poorly understood. Research to fill these gaps for key species and habitats should be undertaken to refine connectivity networks to inform site placement for restoration activities. Benthic invertebrates and species living in deep-sea habitats are particularly poorly known in this respect. Hypotheses of source/sink relationships established with modelling can be tested using genetic and other data types to validate the modelled results.	Incorporation of iterative examination of connectivity networks into monitoring plans (nationally and internationally) and the associated validation work should be conducted over the long term in order to potentially explain any changes to emigration/immigration that might influence recovery success.

Topic (group)	Short-term (<2 years)	Medium-term (2 – 5 years)	Long-term (>10 years)
Active Restoration	Improve marine current/turbulence models to better predict juvenile motions. Most keystone species for reefs and beds have a pelagic juvenile phase, and if most juveniles drift away, due to marine currents and turbulence, one never attains self-sustaining reefs and beds.	Determine the minimum area and density of start populations, given currents and turbulence rates. Knowledge gap on predicting and/or stimulating settlement of juveniles, in or closely around start populations of keystone species for habitat restoration, such as shellfish and seagrass.	Determine stimulating techniques (cues) for juvenile settlement of various species groups.

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Annex 1: List of participants

Name	Institute	Country (of institute)
Alessandra Savini	University of Milano-Bicocca	Italy
Andrew Kenny	CEFAS	UK
Anete Fedorovska	EC	
Ashley Hemraj	DTU	Denmark
Chris Smith	HCMR	Greece
Cristina Canella	ICES/ University of Milano-Bicocca	Italy
Daniel van Denderen	DTU	Denmark
Daniela Diz	HWU	UK
David Reid	ICES	
Eirini Glyki	EEA	
Elena Balestri	SFF	UK
Elina Virtanen	SYKE	Finland
Ellen Kenchington	DFO-MPO, Bedford Institute of Oceanography	Canada
Emma Doherty	Plymouth University	UK
Gary Banta	SDU	Denmark
Harald Hasler-Sheetal	ICES	
Hein Sas	NORA/NERA	
Heini Kujala	University of Helsinki	Finland
Helle Torp Christensen	DTU	Denmark
Indra Semjonova	Latvian Institute of Aquatic Ecology	Latvia
Ingrīda Andersone	Latvian Institute of Aquatic Ecology	Latvia
Isabel Sousa Pinto	University of Porto	Portugal
Ivana Stojanovic	Submariner Network	
Jan Geert Hiddink	Bangor Ocean Sciences	UK
Jens Kjerulf Petersen	DTU	Denmark
Jose Irusta	IEO	Spain
Karolin Adorf	BioConsult SH	Germany

Name	Institute	Country (of institute)
Katrina Bromhall	Natural England	UK
Kjell Magnus Norderhaug	IMR	Norway
Lasse Kurvinen	Metsähallitus Parks & Wildlife Finland	Finland
Maddalena Visser	EC	
Mark Dickey-Collas	Consultant	
Mirta Zupan	EC (JCR-ISPRA)	
Nadia Papadopoulou	HCMR	Greece
Nuno Oliveira	SPEA	Portugal
Oscar Bos	WUR	Netherlands
Patricia Handmann	Lhyfe SA	France
Penina Blankett	Ministry of the Environment	Finland
Peter Evans	Bangor Ocean Sciences	UK
Rebecca Langton	Marine Directorate of the Scottish Government	UK
Roberto Danovaro	MERCES	
Ryan Dunne	ICES	
Sanna Kuningas	LUKE	Finland
Sarah Camilleri	MCAST	Italy
Sebastian Valanko	ICES	
Simonetta Frascetti	University of Naples	Italy
Sonja Fortuin	Ministry of Agriculture, Fisheries, Food Security and Nature	Netherlands
Tallita Tavares	Federal University of Ceará	Brazil
Talya tenBrink	University of Rhode Island	US

Annex 2: Resolutions

Workshop on Nature Restoration and Recovery (WKREST)

2024/WK/HAPISG09 **Workshop on Nature Restoration and Recovery** (WKREST), chaired by Ellen Kenchington*, Canada; Daniël van Denderen*, Denmark; and Jan Hiddink*, UK; will meet at the ICES HQ, Copenhagen, Denmark & online, 4–7 March 2025 (4 days) to:

a) Summarise available methods (including strengths and weaknesses) to model predictions of recovery times of marine habitats and species, the parameters and data required to apply these methods, and describe additional evidence needs to predict the effects of management measures intended to achieve restoration.
The workshop will engage as wide as possible representation of ecosystem components i.e. fish, marine mammals, benthos, birds, etc. as well as considering "ecosystems" as a whole such as trophic interactions (i.e. eutrophication in the Baltic and Black Sea).

b) Summarise available methods to monitor and assess the rate of recovery of marine habitats and species, the resources required to apply these methods, the scales of implementation and their statistical power to detect recovery on defined timescales. Identify additional evidence needs to guide effective monitoring and assessment of the effects of management measures intended to achieve restoration.

c) Review and report on available methods to quantify habitat connectivity, and to monitor and assess changes in connectivity, with a focus on benthic species and habitats of the continental shelves and deep-sea. Report on the implications of habitat connectivity for recovery rates and restoration, and priority evidence needs.

d) Report on the ways in which existing data streams/ calls and methods adopted by the ICES Data Center and expert groups may contribute to meeting evidence needs and priorities identified in ToR a-d.

e) Summarise available and proposed measures and potential threats to achieving the active restoration of marine habitats, their state of development (e.g. from experimental to large-scale trials and applications), relative benefits and costs, and effectiveness. Identify additional evidence needs to evaluate the costs and benefits of active restoration.

f) Review the current use of ecological restoration objectives in marine management and policy and identify the set targets.

The WKREST will report by 31 March 2025 for the attention of ACOM and SCICOM.

Priority	High, a range of policy drivers focus on restoration of species, habitats and ecosystem functions and yet the science basis to inform implementation and the monitoring of the effects of these policies is fragmented. This WK will bring together a diversity of experts to provide the insights needed to establish a WG on restoration ecology and define a workplan that advances ICES capacity to provide expertise, science and advice of relevance to the monitoring and assessment of restoration/recovery and policy implementation and monitoring. Relevant policy drivers include Kunming-Montreal Global biodiversity framework (2022) (Targets 2 and 10), Regulation (EU) on Nature Restoration (2024) (Article 5), and UNGA Resolutions 77/118 (2022) and 78/68 (2023). The development of an evidence-base on modelling and measurement of recovery also has wider relevance for methods being developed to support science and advice related to the Marine Strategy Framework Directive (2008) and associated national and international regulations and policies.
Scientific justification	The overall justification for the WK is to develop and highlight ICES expertise and engagement in an area of growing policy relevance, building a cross-disciplinary team of scientists with interests in restoration ecology (and potentially increasing their opportunities to access research funding), and providing a basis to support future advice requests linked to policies such as UNGA Resolutions and the EU Nature Restoration Regulation. ToR [a] and ToR [b] provide essential insight into how the science community will advance prediction and measurement of rates of recovery of habitats and species. The workshop will engage as wide as possible representation of ecosystem components i.e. fish, marine mammals, benthos, birds, etc. as well as considering "ecosystems" as a whole such as trophic interactions (i.e. eutrophication in the Baltic and Black Sea). This will meet evidence needs of direct relevance to policy commitments to 'nature restoration' as well as providing new understanding of the community and population dynamics of habitats and species. Relevant ICES Science Plan codes 2.2, 2.3, 6.2, 6.3, 6.4. ToR [c] provides scientific insight into links between species and their environment. Such insight is needed to inform policies such as the EU Nature Restoration Regulation and UNGA resolutions related to Vulnerable Marine Ecosystems (VME) that in 2022 and 2023 highlight 'associated and dependent species' alongside the VME habitat. Relevant ICES Science Plan code 6.2. ToR [d] provides a basis for strengthening the evidence base related to habitat connectivity, an essential ecological process and a factor influencing recovery and restoration potential (source and sink dynamics). Connectivity is mentioned explicitly as a management consideration in UNGA resolutions related to VME and the Kunming-Montreal Biodiversity Framework and the EU Nature Restoration Regulation. Relevant ICES Science Plan codes 1.4, 2.3 and 6.2. ToR [e] is intended to help the ICES community work in an efficient way, by identifying and responding to links between emerging needs for science related to recovery/ restoration and existing science and advice on related topics. Relevant ICES Science Plan code 3.2. ToR [f] relates to an area of science that is not actively developed in the ICES community at present. The WK provides an opportunity to consider the pros and cons of active restoration, given interest in the policy arena and some ongoing trials internationally, and to identify the extent to which the ICES community may contribute.
Resource requirements	Negligible beyond standard Secretariat support
Participants	Technical Workshop with researchers and RSCs investigators. If requests to attend exceed the meeting space available ICES reserves the right to refus participants. Choices will be based on the experts' relevant qualifications for the Worksho

	Participants join the workshop at national expense.
Secretariat facilities	Secretariat support and meeting room.
Financial	No financial implications
Linkages to advisory committees	SCICOM, ACOM.
Linkages to other committees or groups	WGFBIT, WGDEC, WGMBRED, WGMHM, WGECO, WGMPAS, WGVHES
Linkages to other organizations	EC, OSPAR, HELCOM, NEAFC, FAO.

Annex 3: Active restoration projects

WKREST prepared an Active Restoration template for the workshop, which participants completed. These templates help identify commonalities and differences across projects and assess best practices. The templates cover four restoration projects:

- Restoration of offshore flat oyster reefs in Belgian marine waters;
- Restoration of kelp forests along the Norwegian coast;
- Restoration of seagrass in Arrábida, coastal mainland Portugal;
- Restoration of bladderwrack (*Fucus vesiculosus*) in the Gulf of Riga.

Active Restoration - Belreefs project

Activity: This pilot project aims to explore a method to restore and establish self-sustaining offshore flat oyster (*Ostrea edulis*) reefs. Suitable substrate seeded with oysters will be installed on marine gravel beds where the oyster reefs once existed off the Belgian coast. The project will be monitored for several years. It is part of the Program of Measures for the Belgian marine waters (MSFD-Natura 2000) and is part of the LIFE B4B (Life Biodiversity 4 Belgium) project. This pilot will form the basis for upscaling efforts in the context of reef restoration, which are also objectives implied by the Nature Restoration Regulation.

Assessment Component:

- Describe the degradation before the implementation started:

> The Belgian part of the North Sea once harbored large-scale flat oyster (Ostrea edulis) reefs, particularly in the Hinderbanken area. These constitute species-rich habitats, but completely disappeared in the beginning of the 20th century, largely due to overfishing and diseases.

Planning and Design Component:

- Describe the specific targets of the restoration action:

> Target: to initiate a flat oyster reef, with its characteristic associated biodiversity. The ultimate objective is the restored reef becomes self-sustaining, without requiring further human interventions in the future.

- Describe the geographic scale of the implementation and how the area has been selected:

> Candidate-location areas have been evaluated based on a series of key criteria, including areas where flat oyster reefs were once present and where current physical conditions are still conducive to oyster growth and survival. In addition, naturally protected areas were selected to protect the artificial reefs from fisheries. This means that marine valleys and areas protected by marine dunes, as well as locations near ship wrecks were preferred. Moreover, in autumn 2024, the sea floor at the considered areas was surveyed using a variety of techniques, in order to map the locations' characteristics and to confirm their suitability for reef restoration. The above activities led to selection of reef deployment areas: several 100 m2 (see below).

- What restoration activities have been conducted and/or are planned?

> In 2025, substrate will be deployed at the selected location, with flat oysters settled on it. The supply of larvae to be settled will be several millions, originating from a dedicated flat oyster hatchery. The technique of 'remote setting' (i.e. settling on substrate near the deployment location, instead of in the hatchery) will be used as well, to facilitate logistics and to promote local production of pre-seeded artificial reefs. The deployment area will run into several 100 m2. The technique of deployment of a high

> amount of oyster spat on robust substrate), combined with remote setting is innovative and most probably offers the best chance of flat oyster reef restoration in the offshore environment. Belreefs is the first project where this technique is employed in European offshore waters.

- What is the expected timescale by which the restoration target(s) should be achieved? And describe how this has been estimated/projected:

> It is as yet unknown whether the amount of oysters and substrate will be sufficient to start a self-sustaining reef. It will probably take 5-10 years of monitoring to be able to evaluate the evolution of the created reef.

Management Component:

- Detail the origin of this action and the specific 'agreement' under which the activity is being carried out, such as a LIFE project with regional permits, a national project, etc.

> The project is commissioned by the Belgian Federal Government (Federal Public Service Health, Food Chain Safety and Environment), with LIFE subsidy (LIFE B4B) and executed by a consortium of oyster, marine operations and survey experts, i.e. Jan De Nul nv, Mantis Consulting, Shells & Valves, and the Royal Belgian Institute of Natural Sciences. It is executed as part of the Belgian Federal Marine Program of Measures 2022-2027, within the framework of the Habitat directives and MSFD.

- What kind of management is needed to achieve the restoration objectives?

> Measures will be taken so that bottom disturbance is excluded from the project site. Efforts are ongoing to establish a marine reserve with fishery measures. This is done by many stakeholder consultations, and efforts are also ongoing to create a community of nature restoration engagement. Monitoring will reveal the status of the project and if this appears necessary, measures can be taken to improve the project set-up (extra substrate, more oysters etc.).

Monitoring and Evaluation Component:

- Describe the monitoring that is put in place to measure progress towards the restoration target(s) and the parameters/indicators that are being monitored:

> The following parameters will be measured, with a variety of techniques:
> 1. Environmental variables: Turbidity, plankton, temperature, salinity, stratification, turbulence and current speed;
> 2. Population variables of the oyster population: Survival, growth, condition, gonad development, larval production, recruitment;

- Have you estimated the statistical power, i.e. the probability to detect if the desired results are achieved, of your monitoring plan? If yes, what is the power to detect successful restoration on (your) defined timescales?

> A power analysis is not required, since the population and biodiversity analysis which are part of the monitoring program will reveal whether the reef is indeed developing, with the associated flora and fauna.

Remarks:

- If the restoration activity were to start now, what would you do differently:

> The project has just started and many learnings from successes and challenges of other offshore projects were incorporated (see below), so that – hopefully – there will not be many aspects to be done differently. But one never knows.

- How important is this restoration activity in relation to the broader ecological status of the target species / area:

> Flat oyster reefs constitute a key habitat in the North Sea. It is broadly recognized that the disappearance of the reefs caused a huge loss of marine bioproductivity and biodiversity. It will by no means be easy to get the reefs back, certainly in the turbulent and dissipative offshore environment, but it has to be attempted. The Belreefs project is a model project, in the sense that many other flat oyster reef restoration projects in the North Sea were studied before the project was undertaken and that learnings of success and failures were translated into the innovative project design.
>
> Relative to the original North Sea flat oyster reef area (more than 10,000 km2), the project is very small, but that is inherent in the current pioneering stage of offshore flat oyster reef restoration.

- Please provide any published frameworks/protocols that you have followed to design, execute and/or evaluate the action:

> The Native Oyster Restoration Alliance (NORA) has published its European Native Oyster Habitat Restoration Handbook in 2020, followed by the Monitoring Handbook (2021) and Site Selection Checklist (2021). These were all followed in the design of the basic principles of the Belreefs project. However, these handbooks largely describe flat oyster reef restoration in the nearshore environment. Offshore flat oyster reef restoration is much more difficult and has started relatively late in time (since 2017). Yet, since 2017, several offshore pilots were undertaken in Belgian, Dutch and German waters, so that these could be analyzed before starting the Belreefs project. The NORA community was closely engaged in this (project managers and oyster experts working offshore were consulted, in association with the NORA secretariat). Besides, Hein Sas (NORA head secretary) is engaged by the Belgian Federal Government to supervise the projects' design and execution.

Active Restoration – Norwegian kelp forests

Activity: Restoration of kelp forests along the Norwegian coast (63 to 71 N).

Assessment Component:

- Describe the degradation before the implementation started:

> Large scale (thousands of km2) kelp forests along the norwegian coast (63 to 71 N) by sea urchins. Loss of Saccharina forests in the Skagerrak

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Planning and Design Component:

- Describe the specific targets of the restoration action:

> Institute of Marine Research have been asked to make a plan for restoring norways kelp forests by the Ministry of Trade, Industry and Fisheries to follow up Parliament decision 789, 2024

- Describe the geographic scale of the implementation and how the area has been selected:

> An action plan will be made by 2026.

- What restoration activities have been conducted and/or are planned?

> Urchin barrens: Quick lime to remove sea urchins, urchin harvest commercially, MPAs, deployment of wolffish (urchin predators), artificial reefs.
>
> Skagerrak: research on future proofing kelp, resilience against marine heatwaves (MHWs). Management actions to reduce eutrophication (runoff, sewage etc)

- What is the expected timescale by which the restoration target(s) should be achieved? And describe how this has been estimated/projected:

> Not decided.

- In designing the active restoration project, did you consider the connectivity of species/habitats with neighboring species/habitats? And, if yes, explain how.

Yes, connectivity will be considered in relation to source populations for recovery of kelp etc

Management Component:

- Detail the origin of this action and the specific 'agreement' under which the activity is being carried out, such as a LIFE project with regional permits, a national project, etc.

Parliement decision 789 (2024) " Stortinget ber regjeringen legge frem en plan og foreslå tiltak for å systematisk restaurere norsk tareskog langs kysten for å bedre det marine miljø»

- What kind of management is needed to achieve the restoration objectives?

To be decided but likely include active and passive restoration (including well-regulated and enforced MPAs) as part of the management toolbox, ecosystem-based management, fishery management, spatial planning etc.

Monitoring and Evaluation Component:

- Describe the monitoring that is put in place to measure progress towards the restoration target(s) and the parameters/indicators that are being monitored:

To be decided (but ecosystem based and adaptive monitoring starting before actions is important)

- Have you estimated the statistical power, i.e. the probability to detect if the desired results are achieved, of your monitoring plan? If yes, what is the power to detect successful restoration on (your) defined timescales?

Not yet.

Remarks:

- If the restoration activity were to start now, what would you do differently:

It hasn't started yet

- How important is this restoration activity in relation to the broader ecological status of the target species / area:

Kelp forests are an important part of the larger coastal ecosystem providing numerous ecosystem services incl food, habitats, nursery and feeding areas, coastal protection etc and they have a potentially important role in carbon sequestration (blue carbon).

- Please provide any published frameworks/protocols that you have followed to design, execute and/or evaluate the action:

Not yet available.

Active Restoration – Seagrass restoration in Arrábida

Activity: Restoration of seagrass in Arrábida (coastal Portugal mainland). The project is aiming to secure a network of healthy seagrass habitats present along the coast of Portugal Mainland and Iberian Peninsula.

Assessment Component:

- Describe the degradation before the implementation started:

> Seagrass were extinct until 2007 in Arrábida (coastal Portugal mainland), before a restoration project started (LIFE BIOMARES). In Ria Formosa (coastal lagoon complex in Algarve, Portugal), seagrass habitat has been lost over the last decades due to several pressures (invasive species, fishing, shellfish harvesting, industrial saltpans, aquacultures, tourism, etc). Target species include *Zoostera marina*, *Z. noltei*, *Ruppia* spp., etc.

Planning and Design Component:

- Describe the specific targets of the restoration action:

> Under the scope of LIFE RestoreSeaGrass:
>
> - 168 ha (1.68 km2) of seagrass will be conserved and not lost thanks to the conservation measures, plus 7 ha (0.07 km2) will be planted new by the restoration activities.
> - 39 species, including seagrass, fish and birds will benefit from the habitat restoration
> - The project will remove at least 1 km2 of an invasive algal species

- Describe the geographic scale of the implementation and how the area has been selected:

> The project is quite local although aiming to secure a network of healthy seagrass habitats present along the coast of Portugal Mainland and Iberian Peninsula. The selected sites are important historic or recent seagrass beds. In Arrábida, restoration started 2 decades ago. The lessons learn are now planned to be replicated in Ria Formosa coastal lagoon.

- What restoration activities have been conducted and/or are planned?

> - Planting seagrass in areas where the species disappeared due to humane activities;
> - Cultivation of rare declining seagrass species integrated in fish farms with manipulated conditions that have been tested for a proof of concept of effectiveness;
> - Remove invasive algal species.

> - Develop the first seagrass restoration demonstration nature park, integrating activities of birdwatching to attract volunteers to participate in seagrass restoration.

- What is the expected timescale by which the restoration target(s) should be achieved? And describe how this has been estimated/projected:

> After the end of the project (7 years) the first 7 ha will be restore and 5 years after the end of the project 5 more ha are estimated to benefit from the project restoration. Also an initial area of 168 ha is planned to be conserved (by enhancing protection and removing invasive species). The bird and fish communities are expected to benefit from the intervention, namely by improving breeding productivity and population sizes.

- In designing the active restoration project, did you consider the connectivity of species/habitats with neighboring species/habitats? And, if yes, explain how.

> Yes, the project will be implemented in a small portion of the large coastal lagoon complex in Ria Formosa. The remaining habitats are expected to benefit from the intervention and from the monitoring implemented under the scope of LIFE RestoreSeaGrass. Also, there are important seagrass sites between the two project sites and beyond where the project partners are working or are networking with other organizations in order to keep aligned interventions and enhance connectivity. Also, monitoring the effect on birds, which have broader vital areas than the project sites will enhance connectivity, namely among the feeding, resting and breeding areas.

Management Component:

- Detail the origin of this action and the specific 'agreement' under which the activity is being carried out, such as a LIFE project with regional permits, a national project, etc.

> The intervention is being implemented under the scope of the LIFE RestoreSeaGrass project, which count with the participation of the National Authority for the Nature Conservation as partner.

- What kind of management is needed to achieve the restoration objectives?

> - In case the project results suggest appropriate adaptations and changes to the existent management plans in place for each site, these will be readily taken into consideration to be included in a future review of those plans.
> - Stakeholders will be involved in several ways. Several sectors of the society are effective partners of the project, namely representatives of the saltpans exploitation (Necton), fish farming (PVL), government (ICNF), academy (CCMAR, ISPA and CSIC) and civil society (the NGOs SPEA and Ocean-Alive). A stakeholder committee will be created and meet periodically to follow up on the project achievements. A program ADOPT-A-SEAGRASS will be created.

Monitoring and Evaluation Component:

- Describe the monitoring that is put in place to measure progress towards the restoration target(s) and the parameters/indicators that are being monitored:

  - Evaluation of seagrass enhancement of diversity, density, mean size, growth,
    survival and production.
  - Transplants will be monitored every season, area, density and canopy height will be registered.
  - Evaluation of seagrass carbon sequestration: mature vs restored vs lost seagrass habitat;
  - Monitoring to evaluate seagrass enhancement of nursery functions - larval and juvenile fish
  - Monitoring by underwater visual surveys and Baited Remote Underwater Videos (BRUV) to evaluate seagrass enhancement of habitat use by fish.
  - Monitoring by visual surveys and cameras to obtain info on seabird and waterbirds (use of the site for feeding, diet, breeding productivity and population size) to evaluate the habitat interventions.
  - Monitoring fishing assemblages in seagrass vegetated and unvegetated habitats and estimate abundance, density, and seagrass enhancement of density, growth, survival and production.

- Have you estimated the statistical power, i.e. the probability to detect if the desired results are achieved, of your monitoring plan? If yes, what is the power to detect successful restoration on (your) defined timescales?

  No, it was not made due to lack of capacity.

Remarks:

- If the restoration activity were to start now, what would you do differently:

  -

- How important is this restoration activity in relation to the broader ecological status of the target species / area:

Seagrass beds are highly biodiverse marine ecosystems that sustain local fisheries, provide coastal protection, increase water and sediment quality, and function as important Blue Carbon stocks. Southwestern Europe contains the most diverse seagrass populations of Atlantic mainland Europe, with several species (Zostera marina, Cymodocea nodosa, several Ruppia spp., Zostera noltei) co-occurring together in the sublittoral zone, but despite their importance they are globally under high human pressure.

- Please provide any published frameworks/protocols that you have followed to design, execute and/or evaluate the action:

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Active Restoration – Restoration of bladderwrack

Activity: EST-LAT Interreg project: Restoration and sustainable management of bladderwrack (*Fucus vesiculosus*) in the Gulf of Riga.

Assessment Component:

- Describe the degradation before the implementation started:

> General environmental degradation due to ongoing eutrophication of the Baltic Sea and climate change related browning of the Gulf of Riga waters, decreasing the *Fucus vesiculosus* depth range from 8m depth to 4.5m depth.

Planning and Design Component:

- Describe the specific targets of the restoration action:

> Restoration is planned at 2 pilot sites in the southern part of Gulf of Riga (Latvian territory) and 2 pilot sites in northern part of the Gulf of Riga (Estonian territory)

- Describe the geographic scale of the implementation and how the area has been selected:

> Initially, small restoration area (100 x 100m) in each place is planned. Areas are selected nearby healthy Fucus communities to enlarge the existing area and maintain connectivity to nearby populations.

- What restoration activities have been conducted and/or are planned?

> Planned restoration activities are:
>
> - Transplantation of attached plants to nearby location choosed for restoration;
> - Placement of artificial substrate near the healthy generatively reproducing plants, to enhance settlement of seedlings
> - Cleaning of natural substrate overgrown by annual algae near the healthy generatively reproducing plants, to enhance settlement of seedlings
> - Laboratory experiments to regrow the adventitious branches of Fucus vesiculosus on artificial substrate

- What is the expected timescale by which the restoration target(s) should be achieved? And describe how this has been estimated/projected:

At the 3rd year of project we hope to see the results of restoration experiments, but restoration sites will be include in monitoring program of coastal habitats.

- In designing the active restoration project, did you consider the connectivity of species/habitats with neighboring species/habitats? And, if yes, explain how.

We considered that Gulf of Riga is relatively small waterbody with internal water circulation and limited exchange with open Baltic (Jonsson et al, 2020), therefore donor sites would be located around Sarema island with better growth conditions, while recipient sites would be on hydrodinamicaly active southern part of the Gulf, where growth conditions are more demanding and substrate distribution fragmented

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Management Component:

- Detail the origin of this action and the specific 'agreement' under which the activity is being carried out, such as a LIFE project with regional permits, a national project, etc.

EST-LAT Interreg project

- What kind of management is needed to achieve the restoration objectives?

For sustainable management of Fucus communities in the Gulf of Riga would be necessary to reduce eutrophication and restrict the use of area for coastal fisheries. Both issues are unsolved and stakholders unsupportive.

Monitoring and Evaluation Component:

- Describe the monitoring that is put in place to measure progress towards the restoration target(s) and the parameters/indicators that are being monitored:

Not there yet.

- Have you estimated the statistical power, i.e. the probability to detect if the desired results are achieved, of your monitoring plan? If yes, what is the power to detect successful restoration on (your) defined timescales?

No, because these are small scale pilot studies.

Remarks:

- If the restoration activity were to start now, what would you do differently:

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- How important is this restoration activity in relation to the broader ecological status of the target species / area:

Restoration of the Fucus population is important at national and regional level, as this is the habitat-forming species, that provides habitat and shelter for numerous organisms and thereby are known as important hotspots of biodiversity. Changes in the structure of the F. vesiculosus community will also affect the ecology of the associated organisms. Besides Fucus population are important spawning grounds for Gulf of Riga herring population.

- Please provide any published frameworks/protocols that you have followed to design, execute and/or evaluate the action:

Marine Ecosystem Restoration in Changing European Seas MERCES *Grant agreement n. 689518,* D 3.2: Criteria and protocols for restoration of shallow hard bottoms and mesophotic habitats. Report, 2017