D1.1: State of the knowledge on European marine habitat mapping and degraded habitats

Marine Ecosystem Restoration in Changing European Seas MERCES

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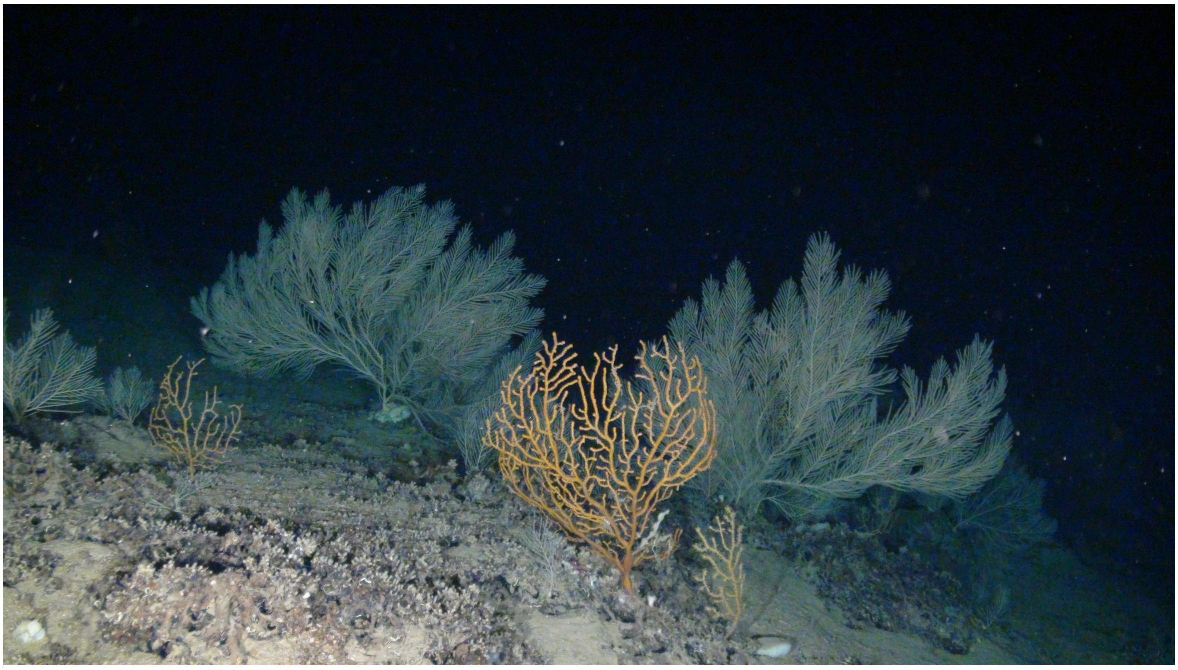

Callogorgia verticillata and *Acanthogorgia hirsuta*, Ses Olives seamount (Balearic Islands). Photo by © OCEANA

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Summary

During the last decades, several EU Directives and other international legislations have generated a large number of national initiatives (e.g. marine atlases) and EU programmes on habitat mapping. Nevertheless, the outcomes of these initiatives are fragmented and, to our best knowledge, to date there is no systematic assessment regarding the nature, quality and availability of information across the European seas. One of the main goals of the MERCES project (www.merces-project.eu) is to produce a census of available maps of European key marine habitats, along with their degradation status and restoration potential in the European Seas, providing a potential basis for future discussion on restoration activities.

MERCES is producing a census of European marine key habitat maps, degraded habitat maps and investigating key habitat restoration potential. To do this MERCES has

i. reviewed known existing habitat maps of European regional seas and provided source citations for all of the information
ii. reviewed degraded habitat map resources by regional sea and habitat type (e.g. seagrass, macroalgae, coral gardens, sponge aggregations, seamounts, vents), associated habitat deterioration (e.g. extent of decline), the most common human activities and pressures reported, and the recovery and restoration potential of these habitats
iii. reviewed 6 key habitats (including kelp and macroalgal forests, seagrass meadows, coralligenous assemblages, coral gardens and deep-sea bottom communities) and linked 6 major habitat features, such as dynamics, connectivity, structural complexity and vulnerability, to consequences for restoration and the likelihood of restoration success

Catalogue for existing habitat maps and degraded habitat map resources

To achieve the goal of reviewing habitat maps and degraded habitat map resources, we performed an extensive review of existing information and compiled a catalogue with mapping sources for marine habitats of conservation interest, covering different levels of the EUNIS habitat classification system, as well as degraded marine habitat. A total of 577 entries were catalogued (Habitat catalogue: 376 entries, Degraded habitat catalogue: 201 entries), containing maps depicting the distribution of habitats within all major European seas as well as at a global scale. The majority of entries are for the Mediterranean Sea (44%), followed by those from the North-East Atlantic Ocean (32%), the Baltic Sea (13%) and a small percentage from the Black Sea (3%). Moreover, 8% of the entries concerned non-EU Regional Seas and/or global maps. Sublittoral soft and hard substrate habitats dominated (27% and 26%, respectively), followed by deep-sea habitats (24%) and broad scale maps (21%). The results of the analysis revealed differences in habitat type records between sea basins and MSFD regions or sub-regions, reflecting both habitat heterogeneity between different biogeographical areas and possibly where research efforts and

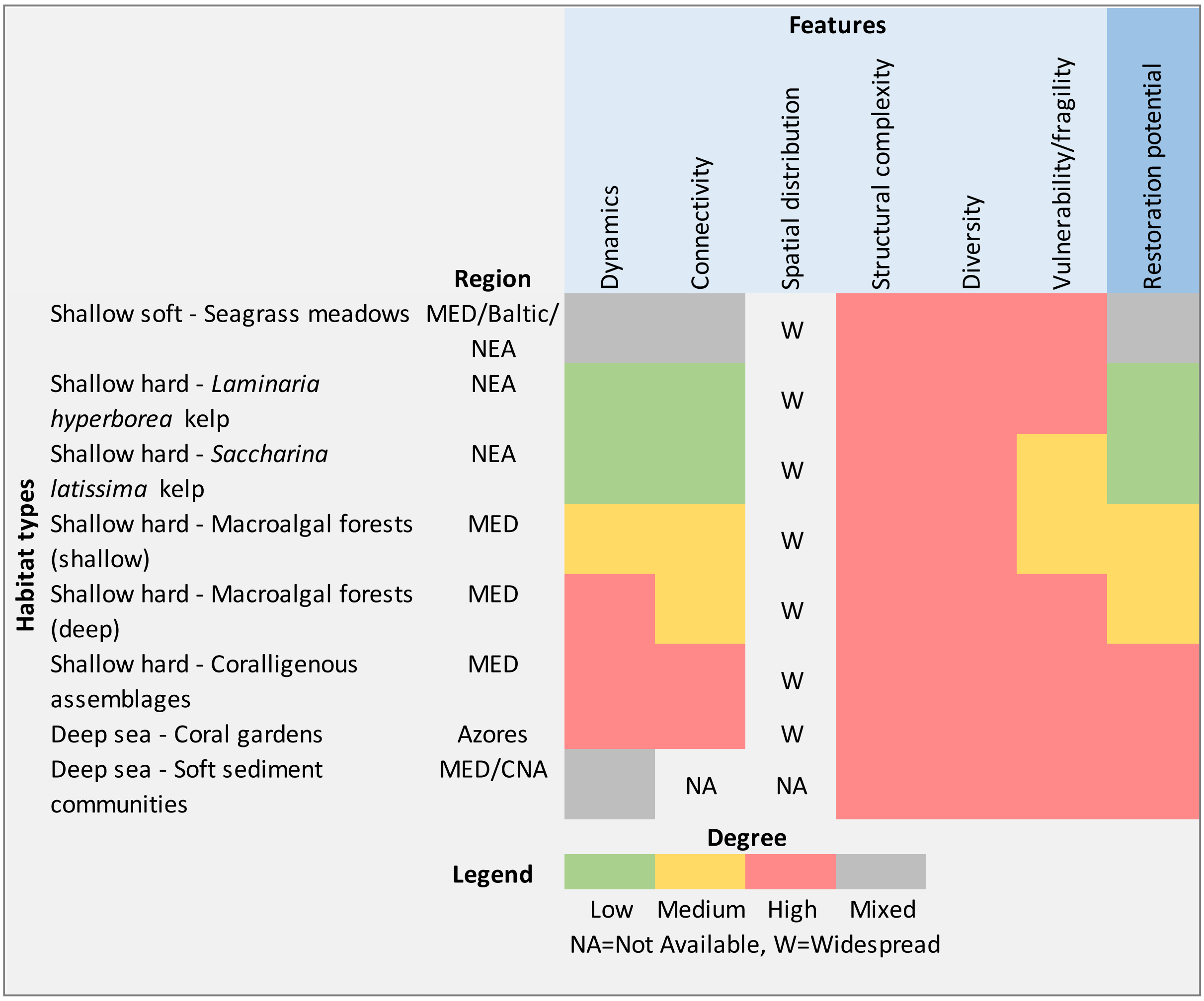
stakeholder focus have been placed within the last few decades. Although the catalogues included a considerable number of priority and/or protected species and habitats (44%), a low percentage of the entries (9%) originated from Marine Protected Areas (MPAs). The state of habitat degradation has been assessed in only 56 map entries in the framework of large-scale habitat assessments undertaken by international organizations and commissions, which mainly represent habitats in an unfavourable status in the North-East Atlantic and the Mediterranean Sea. Information on the extent of decline of habitats was of descriptive/qualitative nature or was absent in most catalogue map entries (37% each), while very few sources included information on the recovery/restoration potential of the examined habitats (40%), and then mainly based on expert opinion. Mitigation and/or removal of activities causing habitat degradation and their impact (e.g. restrictions to fishing activities and MPAs) was the most frequently recommended practice (20%) while active restoration was rarely suggested (only in 5% as a sole activity and combined with mitigation in another 2%), probably due to (a) the logistical constraints and cost of applying active restoration at large scales (e.g. regional level) or (b) the lack of mapping initiatives focusing on restoration activities. Catalogue entries were mainly sourced from grey literature and web sources for existing habitats (61%) and from peer-reviewed papers for degraded habitats (67%). In both cases, the majority of sources provided only images of maps (84% in total), while accessible GIS layers and online map viewers accounted for small percentages (7% and 9%, respectively), limiting the possibility of data extraction and further use of habitat inventory data (e.g. for conservation planning initiatives or the compilation of maps). Finally, our review revealed several gaps regarding the thematic, temporal and geographic coverage of the available map resources, as well as the resolution, availability and data format of the map resources, which should be considered and standardized in future mapping initiatives.

Features of key habitats concerning restoration

To achieve the goal of reviewing key habitats and the major features having an influence on the likelihood of restoration success, the MERCES group of experts selected case study habitats to represent the MERCES focal habitat types (shallow soft bottom habitats, shallow hard bottom habitats and deep-sea habitats), in which restoration activities are taking place. The case study habitats selected are

- Mediterranean, Baltic and North Atlantic seagrass meadows
- North-East Atlantic kelp forests, i.e. the two habitat building species in Norway, *Laminaria hyperborea* and *Saccharina latissima*
- Mediterranean Sea macroalgal forests, shallow and deep *Cystoseira* spp.
- Mediterranean coralligenous assemblages
- Coral gardens in the Azores
- Deep-sea bottom communities in the Mediterranean basin and Central-Northern Atlantic

Following a MERCES workshop, the following key important, but generic features were identified in order to systematically assess the factors that are relevant to restoration success and thereby the chances of recovery (recovery potential): Dynamics (such as growth rate and longevity), Connectivity (such as dispersal and gene flow), Spatial distribution, Vulnerability/Fragility, Structural complexity (e.g. 3D complexity) and Diversity (including species, functional, genetic and community diversity). For each of the case study habitats this report summarises how the specific characteristics among these features relate to restoration potential (see table below). Green shading relates to a feature that may facilitates achieving the restoration goals, orange shading represents medium and red shading denotes that the feature makes restoration relatively difficult. Grey shading represents conditions where different factors (e.g. species or location) may lead to different degrees of restoration success. NA indicates that there is scarce or no available information. NA indicates that there is scarce or not available information concerning connectivity and spatial distribution (for deep-seas sediment communities). Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; CNA: Central-Northern Atlantic; MED: Mediterranean Sea.



Key conclusions of this review

- More maps are available for certain habitats and areas than others, reflecting research efforts, human use and stakeholder focus in the recent decades.

- An obvious lack of open access and downloadable map files limits further use of these maps.
- A large proportion of the available map resources concerns protected habitats.
- Habitat status is not often assessed, except for EU Directives, IUCN Red Lists, and various cumulative pressure assessments.
- A common understanding and interpretation on how to assess degradation (and thresholds of change) across habitats is lacking.
- Multiple activities and pressures act on the 6 selected case study habitats. The most commonly reported activities include extraction of living resources, renewable energy, oil and gas exploitation, aquaculture and fish farming, coastal and marine structure and infrastructure.
- A challenge for suggesting restoration practices and guidelines is the lack of comprehensive knowledge on the link between a pressure and a change in ecological state or condition.
- *Deep-sea coral habitats* are, together with other *deep-sea bottom communities*, according to our scoring (see Table above), likely to be the most challenging when it comes to achieving acceptable restoration goals. In part this is due to the extremely slow growth rates, long lifespans (thus likely late age of first maturity), low fecundity, high vulnerability to human impacts of key indicator species and the limited information on larvae biology, dispersal and population connectivity. *Coralligenous assemblages*, with slow growth rates, low connectivity, high vulnerability, fragility to human activities and extreme structural complexity, are also challenging to restore. The restoration success of *seagrass meadows* is difficult to assess and depends highly upon the species present and the location of the restoration activity. Shallow-water hard-bottom *macroalgal forests* are classified as "medium" in terms of their likelihood of achieving restoration goals, owing, for some species, to their higher connectivity levels and growth rates but medium to high vulnerability to pressures. Of the case study habitats selected, shallow hard bottom *kelp forests* will most likely have the highest likelihood of restoration success due to their fast growth rates, high levels of connectivity and low levels of vulnerability.
- Mitigation of pressures, prevention of impacts, spatio-temporal regulation of activities, and compensation are still considered the most cost-effective strategies for managing present trajectories of change. Ecological restoration approaches for most habitats should consider the combination of the three restoration approaches (natural regeneration, assisted regeneration and reconstruction).
- Beyond considering external exchanges, species composition, structural diversity and ecosystem functioning, key factors for a successful restoration are synergistic actions such as 1) careful choice of the restoration site, 2) implementation (or knowledge of existing) measures for the reduction of the source of degradation, 3) an appropriate handling of weak features, which induces 4) a reduction of habitat fragility.

CONTENTS

Acronyms used

Acronyms	
Baltic	Baltic Sea
CBD	Convention on Biological Diversity
Black	Black Sea
CMED	Ionian Sea and the Central Mediterranean
CWC	Cold Water Coral
EEA	European Environmental Agency
EEC	European Economic Community
EEZ	Exclusive Economic Zone
EMED	Aegean-Levantine Sea
EIA	Environmental Impact Assessment
EMODnet	European Marine Observation and Data NETwork
EU	European Union
EU28	The 28 EU countries
EU28+	EU28 and the adjacent regions, including Liechtenstein, Norway and Switzerland
EUNIS	European Nature Information System (for habitat classification)
EUSeaMap	The EMODnet broad-scale seabed habitat map for Europe
FAO	Food and Agriculture Organisation of the United Nations
GES	Good Environmental Status
GIS	Geographic Information System
HD	Habitats Directive
HELCOM	HELsinki COMmission (Baltic Marine Environment Protection Commission)
ICES	International Council for the Exploration of the Sea
IMAP	Integrated Monitoring and Assessment Programme
IUCN	International Union for Conservation of Nature
JNCC	Joint Nature Conservation Committee
LEK	Local Ecological Knowledge
MA	Millennium ecosystem Assessment
MAP	Mediterranean Action Plan (UNEP)
MarLIN	MARine Life Information Network (UK)
MED	Mediterranean Sea
MPA	Marine Protected Areas
MSFD	Marine Strategy Framework Directive
MSPD	Maritime Spatial Planning Directive
NGO	Non-Governmental Organisation
OCEANA	International Conservation organization focussing solely on Protecting the World's Oceans
OSPAR	OSPAR Commission (protecting and conserving the North-East Atlantic)
ROV	Remotely Operated Vehicle
SER	Society for Ecological Restoration
SH	Sensitive Habitats
SPA	Specially Protected Areas
TEEB	The Economics of Ecosystems and Biodiversity
UNCLOS	United Nations Convention on the Law Of the Sea
UNEP	United Nations Environment Programme
UNEP-MAP-RAC/SPA	UNEP, MAP, Regional Activity Centre for Specially Protected Areas
VME	Vulnerable Marine Ecosystem
WFD	Water Framework Directive
WMED	Western Mediterranean

Project acronyms

ADRIPLAN	ADRiatic Ionian maritime spatial PLANning
BALANCE	Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning
Baltic MPAs	Marine Protected Areas in the Eastern Baltic Sea
BENTHIS	Benthic Ecosystem Fisheries Impact Studies
COCONET	Towards COast to COast NETworks of marine protected areas
LIFE+INDEMARES	Project for protection and sustainable use of the biodiversity in the Spanish seas
MAREANO	Marine area database for Norwegian oceans
MARMONI	Innovative Approaches for Marine Biodiversity Monitoring and Assessment of Conservation Status of Nature Values in the Baltic Sea
MEDTRENDS	The MEDiterranean Sea: TRENDS, threats and recommendations
MERCES	Marine Ecosystem Restoration in Changing European Seas
MESH	Development of a framework for mapping European Seabed Habitats
MESMA	Monitoring and Evaluation of Spatially Managed Areas
NEMA	Inventory and Development of Monitoring Programme for Nature Values in Estonian Marine Areas
NETMED	Project for Mediterranean habitat maps
ODV	Ocean Data Viewer
PERSEUS	Policy-oriented marine Environmental Research for the Southern EUropean Seas
THAL-CHOR	Cross-border Cooperation for Maritime Spatial Planning Development
VELMU	Finnish Inventory Programme for the Underwater Marine Environment

1. Introduction

1.1. Scope of the Deliverable

The overall scope of MERCES Deliverable 1.1 is to produce a census of key European marine habitat maps, degraded habitat maps, the features (properties) of the habitats and how these relate to the restoration potential. Furthermore, as a basis for restoring habitats efficiently, there is also a need to assess activities and pressures on the degraded habitats. In order to fulfil this scope, we:

i. Reviewed existing habitat maps and provide sources of information of habitats under scrutiny across the European regional seas
ii. Reviewed key and degraded habitats to
    a. Identify features (properties) of selected key habitats and considerations for extent, and spatial and temporal resilience to assist with the concise identification categorisation of degraded habitats and their recovery potential.
    b. Identify evidence of damage (generic and specific) and produce inventories of degraded key habitats in European regional seas.
    c. Review activities and pressures reported from degraded key habitats

When selecting the key focal habitats of the study the MERCES consortium chose, during a WP1 dedicated workshop, selected habitats that cover both shallow and deep areas, soft and hard substrates and had a good geographic spread. In order to be able to provide, in a relatively short time period (48 months), new science-based approaches, methodologies and tools for European marine ecosystems restoration we focused on habitats which have ongoing or planned restoration projects. Based on this, the focal habitats are seagrass meadows (shallow soft) in the Mediterranean, the Baltic and North Atlantic seas, two habitat forming kelp species (shallow hard) in the Norwegian North East Atlantic, macroalgal forests (divided into a shallow and a deep part) and coralligenous assemblages (shallow hard) in the Mediterranean Sea, coral gardens (deep sea) in the Azores and deep-sea bottom communities (open slopes, submarine canyons, deep-sea basins and seamounts) in the Mediterranean basin and Central-Northern Atlantic.

1.2. Background

Worldwide, we are observing widespread habitat loss and degradation in estuarine, coastal and marine systems (Lotze et al. 2006), reducing biodiversity, threatening the multitude of goods and services provided by marine systems (Worm et al. 2006) and decreasing the resilience of the system to future pressures (Folke et al. 2004). The loss and degradation of habitats is caused by a wide range of human activities and pressures (Halpern et al. 2008), including destructive fishing practices (e.g. bottom trawling), overfishing, aquaculture, spread of invasive species, eutrophication, large-scale oil and gas operations, offshore renewable energy developments, coastal engineering, coastal development and climate change (Claudet & Fraschetti 2010).

Ecosystems provide a range of services, many of which are of fundamental importance to human well-being, for health, livelihoods, and survival (Costanza et al. 1997, Millennium Ecosystem Assessment (MA) 2005, TEEB Foundations 2010). These services may be transformed into monetary values in an Ecosystem Service Value Database (ESVD, de Groot et al. 2012), which makes the positive and negative effects of changes, degradation and habitat loss more visible. Putting numbers to the value of marine habitats highlights what is at stake. As an example, the annual economic value of seagrass to fisheries in the Mediterranean Sea is at least €190 million, including about €78 million to commercial fishing (based on value of seafood caught) and €112 million to recreational fishing (based on the overall economic impact of spending by anglers, Jackson et al. 2015). Seagrass also provides other ecosystem services and benefits, so its full economic value is much greater than the €190 million calculated for fisheries.

In response to the current situation and the potential economic costs, numerous conservation efforts have been implemented by agencies, governments and NGOs seeking to prevent and mitigate further losses and to restore, recover or replace ecosystems where possible. Although the restoration science is comparatively new, there is a rich literature on restoration options (from habitat restoration to compensation) and the variety of definitions used in both the marine, coastal and terrestrial environments (Figure 1.1 and list of definitions in Annex 1). In Europe, at least four different EU Directives [i.e. the Water Framework Directive (WFD), the Habitats Directive (HD), the Marine Strategy Framework Directive (MSFD) and the Maritime Spatial Planning Directive (MSPD)] and other international legislation (e.g. United Nations Convention on the Law of the Seas (UNCLOS), Barcelona, OSPAR and HELCOM Conventions) have been promoted to assess and improve the environmental status of marine ecosystems and plan their sustainable use. The current EU environment and climate policy has four interrelated policy approaches to support environmental conservation efforts and sustainably transition to a green economy: - mitigate, adapt, avoid and restore (www.europarl.europa.eu/RegData/etudes/STUD/2014/536288/IPOL_STU(2014)536288_EN.pdf).

It has recently been demonstrated that optimal conservation outcomes can be achieved through the restoration of degraded habitats (Possingham et al. 2015), and under the EU 2020 Biodiversity Strategy there is an ambition to restore at least 15% of the degraded ecosystems within Europe (European Union 2011), with the term "restore" relating to policies and actions that focus on remediating environmental degradation (where possible). Similarly, ecosystems that are deemed not to have reached "Good Environmental Status" (GES, as defined by the MSFD) are expected to receive some kind of restorative action. The aim of the EU project "MERCES" is to help the EU meet their ambitions and commitments by identifying key and degraded habitats, their features and the restoration potential of these habitats.

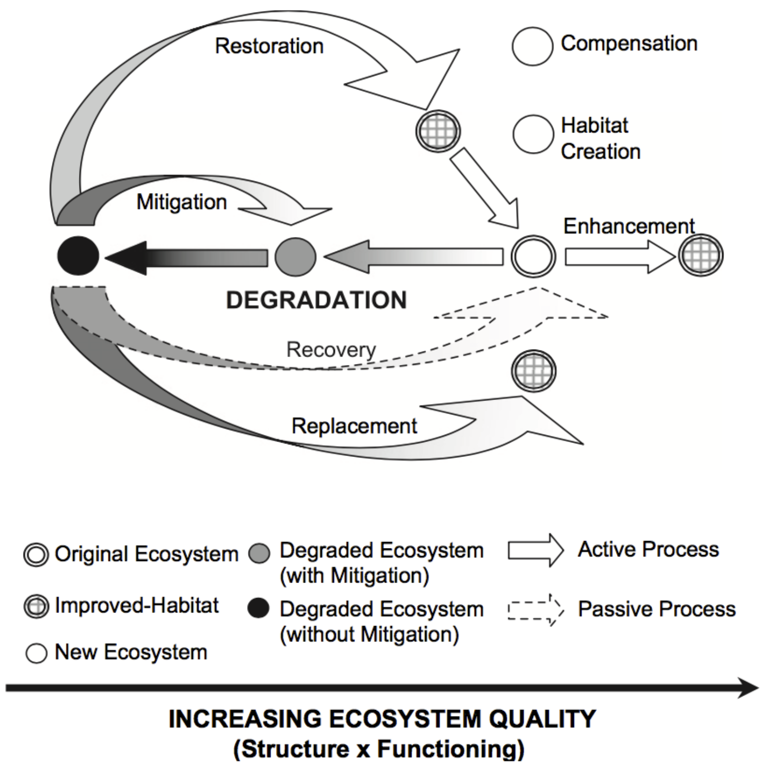


Figure 1.1. Conceptual model illustrating the processes of natural recovery and human-mediated restoration of a degraded ecosystem through which ecosystem quality is increased to an improved or original state (from Elliot et al. 2007). A more comprehensive list of definitions of the different concepts can be found in Annex 1.

1.3. Habitat mapping and degraded habitat map resources

The Convention on Biological Diversity defines habitat as "the place or type of site where an organism or population naturally occurs" (CBD 1992, p. 4). In order to be effective in restoration ("effective" including both the financial costs of the restorative action and the derived ecosystem service benefits, Decleer et al. 2016) it is essential to understand where habitats are located; their spatial extent and their temporal dynamics (long-term trends). The different EU Directives and other international legislation have generated a large number of national initiatives (e.g. marine atlases) and EU programmes on habitat mapping. One of the broad scale examples is EMODnet (European Marine Observation and Data Network) Seabed Habitats (www.emodnet.eu/seabed-habitats), which has produced a broad scale habitat map (Figure 1.2). Its usefulness lies in its standardisation of classification as well as total coverage for the European Seas, which is in accordance with the European Nature Information System (EUNIS, eunis.eea.europa.eu/index.jsp). EUNIS work is still ongoing and aims to harmonise the description and collection of data across terrestrial, freshwater and marine habitats. Annex 2 has a more detailed list of habitat mapping initiatives, conventions and programs in Europe.

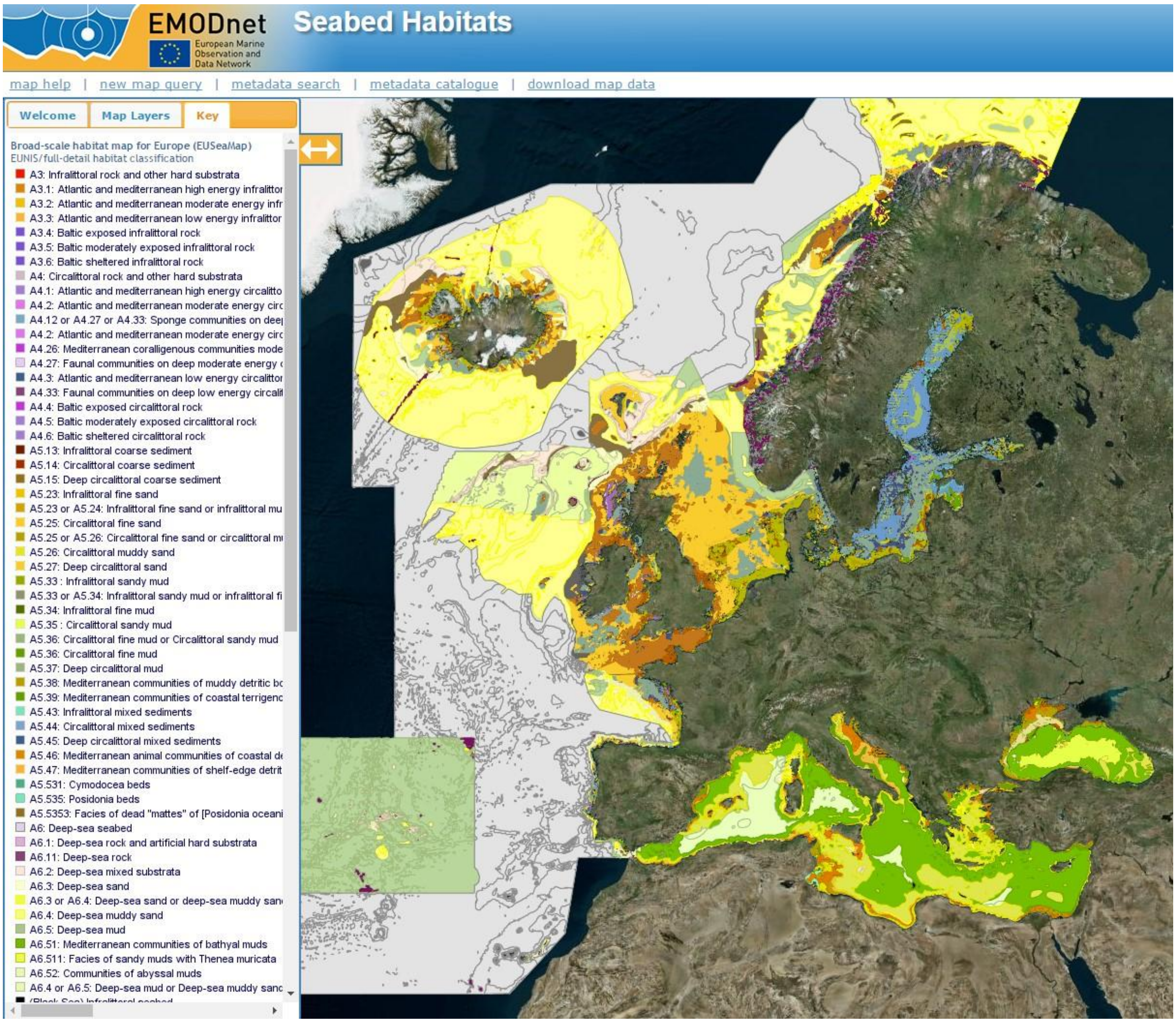


Figure 1.2. EMODnet broad-scale seabed habitat map for Europe (EUSeaMap, www.emodnet.eu/seabed-habitats) according to the EUNIS habitat classification (from online viewer www.emodnet.eu/seabed-habitats). Some habitats and areas are mapped, others are modelled.

Whilst the EUNIS framework ensures habitats are mapped in a standardised way, no such framework exists to report or quantify degradation. However, one potential source of information is the European Red List of marine Habitats, which provides an overview of the risk of collapse (degree of endangerment) of marine habitats in the European Union (EU28) and adjacent regions (EU28+, which also include Liechtenstein, Norway, Switzerland) and thus provides information that can be used to identify habitats and regions in need of restoration (ec.europa.eu/environment/nature/knowledge/redlist_en.htm). The assessments are based on a consistent set of categories and criteria, and detailed data and expert knowledge from the involved countries. A total of 257 benthic marine habitat types has been assessed in a recent overview of the degree of endangerment of marine, terrestrial and freshwater habitats (The European Red List of Habitats, Gubbay et al. 2016). In total, 19% (EU28) and 18% (EU28+) of the evaluated habitats were assessed as threatened in categories Critically Endangered, Endangered and

Vulnerable. The highest proportion of threatened habitats in the EU28 is found in the Mediterranean Sea (32%), followed by the North-East Atlantic (23%), the Black Sea (13%) and then the Baltic Sea (8%). This report provides also an overview of the risk of collapse for 47 benthic habitats in the Mediterranean. Almost half of the Mediterranean habitats (23 habitats, 49%) were defined with Data Deficient in the EU28 countries. Of the remainder (24 habitats) 83% were defined as of conservation concern (NT-CR) with 63% threatened to some degree (42% Vulnerable and 21% Endangered). A good proportion of habitats in infralitoral and mediolitoral environments were defined as either Vulnerable (e.g. *Posidonia* beds) or Endangered (e.g. canopy-forming algae) (forum.eionet.europa.eu/european-red-list-habitats/library/marine-habitats/mediterranean-sea). They include algal-dominated communities on infralitoral sediments and circalitoral sediments and rocks together with mussel and oyster beds. The criteria under which habitats were most frequently assessed as threatened in both the EU28 and EU28+ were decline in extent and a decline in quality.

1.4. Restoration actions

Pollution, eutrophication, fisheries, natural system modification (such as dredging and sea defence work) urbanisation and climate change are the most frequently cited pressures in the Red List of European Habitats affecting the distribution range and conditions of habitats, with variation in importance between different regions/seas (ec.europa.eu/environment/nature/knowledge/pdf/Marine_EU_red_list_report.pdf). Marine Protected Areas (MPAs, www.iucn.org/content/marine-protected-areas-%E2%80%93-why-have-them) are an important tool for protecting marine coastal habitats and seafloor integrity ("integrity" requiring that habitats are not artificially fragmented). However, it is widely recognised that, in addition to the establishment of protected areas, restorative actions are also required to halt further declines in biodiversity (Novacek & Cleland 2001, Abelson et al. 2016a). Ecological restoration has long been used successfully as a management tool in terrestrial ecosystems and it has been shown that the basic principles and attributes can be applied to marine habitats such as mangrove forests, salt marshes, bivalve beds and seagrass meadows (e.g. Bell et al. 2014, Mengerink et al. 2014, Van Dover et al. 2014, Chang et al. 2016, van Katwijk et al. 2016). The object of ecological restoration is degraded ecosystems (McDonald et al. 2016) but available mapping initiatives concern mainly particular habitats, communities or species. However, whilst restoration has been proved effective - with varying degrees of success (Bayraktarov et al. 2016, Montero-Serra et al. 2017) – restoration projects remain expensive and therefore mostly occur on small, local spatial scales over relatively short periods of time (1-2 years).

1.5. Concepts and definitions

Annex 1 presents different definitions dealing with restoration (such as rehabilitation, remediation, recreation, mitigation and compensation) and different types (or degrees) of habitat degradation (such as degraded, damaged, destroyed, transformed, lost and fragmented habitats).

According to the EU Habitats Directive (92/43/EEC), natural habitats are defined as "*terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural*" and its main aim is "*to maintain or restore natural habitats at a favourable conservation status*". The EUNIS defines habitat as "*plant and animal communities as the characterising elements of the biotic environment, together with abiotic factors (soil, climate, water availability and quality, and others), operating together at a particular scale*" (Davies et al. 2004). However, there has been a long debate on the definition of habitat among researchers (e.g. Fraschetti et al. 2008) and policy makers (e.g. in the requirement for assessments by broad habitat types for various EU directives, Galparsoro et al. 2012, 2014), often leading to a conflating and broad use of the term. This broad use of the term habitat is for example close to the definition of ecosystem provided by Clewell & Aronson (2013) as "*the complex of living organisms and the abiotic environment with which they interact at a specified location*". In the current report, we have considered various features (e.g. biological and geological), which correspond to different levels of the EUNIS habitat classification system, supporting communities of special conservation interest. We have included for example habitats from regional lists of threatened or declining habitats (e.g. OSPAR lists include *Zostera* beds and deep-sea sponge aggregations). We have looked at very broad habitat types (e.g. A6 Deep sea, a level 2 EUNIS habitat) that are often seen in global maps or in initiatives mapping human activities. Finally, we have also considered specific ecosystem-engineering taxa (e.g. *Posidonia* meadows, macroalgal/*Cystoseira* forests and coral/sponge gardens), and large physical/geological features such as seamounts and canyons, covering both levels 4 and 5 of the EUNIS habitat classification system.

In order to effectively document and map the degree and extent of degraded habitat, a coherent, comparable and harmonized definition of "*degradation*" is first required. Common definitions and examples of degraded habitats include habitats that have lost, to some extent, ecosystem structure, function and service provision (Abelson et al. 2016a). This could be in comparison with healthy habitats elsewhere or with past states (e.g. historical pristine or recent past), but unless there are clear cut assessment criteria and thresholds (e.g. Keith et al. 2013, IUCN Red List of Ecosystems) the line is often arbitrary (Abelson et al. 2016b for various examples of healthy versus degraded ecosystems). Reflecting this diversity and ambiguity of definitions, information on habitat degradation and restoration potential in the MERCES catalogue entries might vary among sources and to a certain point among experts undertaking this review task. Whilst standardised definitions have been proposed, the terminology and concepts used still result in ambiguity. For example, degradation has been defined as "pertaining to subtle or gradual changes that reduce ecological integrity and health" (Clewell et al. 2004). In addition to the challenges associated with defining and measuring "ecological integrity and health", complexities exist surrounding spatial and temporal scales. For instance, does degradation relate to a decrease in area and/or a change in ecosystem properties and services, are we focused on degradation at large or small scales and are we considering long and short term degradation? Such challenges complicate the development of common approaches and hinder attempts to identify and map marine habitat degradation. Furthermore, degradation means different things to different people, and the way degradation is quantified and mapped reflect these differing points of view. For example, for a conservationist, any change in natural condition can represent "degradation", whilst to a policy maker degradation tends to be more related to the capacity of a habitat to provide goods and services. Additionally, there is a range of terms that are frequently used interchangeably (such as degradation, damage, destruction and transformation), which all represent some form of deviation from the "normal" or "desired" state, or "reference conditions", and are difficult to separate or define. Annex 1 presents different definitions of degraded, damaged, destroyed, transformed, lost and fragmented habitats (from SER 2002, Airoldi & Beck 2007, Elliot et al. 2007, Abelson et al. 2016, McDonald et al. 2016).

Similar to the ambiguity that surrounds the term "degradation", it is a challenge that the term "*restoration*" is perceived differently by different people. In the simplest way, "restoration" is associated with actions such as planting of seagrass and kelps and transplanting mussels and bivalves. Broadly speaking restoration is an active intervention (Elliot et al. 2007). Ecological restoration is an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability. (SER 2004). Furthermore, restoration is considered to be the process of re-establishing a given habitat, in addition to its structure and functioning, as opposed to other actions such as increasing habitat or ecosystem quality (such as rehabilitation, remediation, recreation, mitigation and compensation etc., see Annex 1 for more details). More specifically restoration can be defined as "the process of assisting the recovery and management of ecological integrity", where the term "ecological integrity" includes "a critical range of variability in biodiversity, ecological processes and structures, regional and historical context, and sustainable cultural practices" (McDonald et al. 2016). Ecological restoration, with its emphasis on working with natural processes, is the most efficient and effective means of repairing damage to all intact, semi-natural or degraded local native ecosystems (McDonald et al. 2016).

2. Methods and Materials

2.1. Catalogue compilation

Two catalogues were complied, one documenting sources of information relating to the distribution of habitats within Europe (here after referred to as the "Habitats catalogue") and one documenting the same information for degraded habitats (here after referred to as the "Degraded habitats catalogue"). The catalogues were populated following a semi-structured literature search (Google Scholar) which used keywords and keyword combinations. Keywords included “map”, “marine” and “Europe” and “degraded” (for the Degraded habitats catalogue only) and the examined types of marine habitat, e.g. “maerl”, “coralligenous”, “*Posidonia*”, “*Zostera*”, “seamount”, “canyon” etc., or more general terms and major habitat types, such as “habitat” or “deep sea”, “seagrass” etc. For all the above cases, the first 100 search results were scanned, (a) in order of relevance and (b) ranked by year (15.11.2016 being the most recent. Specific web resources were also searched (including downloadable reports) of national/international organizations (including NGOs), commissions and agencies dealing with habitat conservation (e.g. EEA, IUCN, UNEP-MAP-RAC/SPA, HELCOM, OSPAR, FAO, OCEANA, MarLIN, Scotland’s Marine Atlas) and all the European projects registered in the European Marine Spatial Planning platform (e.g. MEDTRENDS, COCONET, MESMA, PERSEUS, ADRIPLAN, THAL-CHOR, BALANCE). In addition, project participants were asked to provide entries based on their thematic and regional knowledge.

The catalogues are simple Excel workbooks with a single row per entry and a series of columns corresponding to the desired meta-data (described in more detail in the following sections and in Annex 3). The catalogues (Annex 4) were compiled by all project partners and in order to ensure consistency in data entry across partners a ‘Read me’ datasheet (instructions and clarifications) and a ‘List’ datasheet for visualising the options (free text and list) for each column were provided. In order to ensure traceability and data management, an accession number was given to every entry.

2.1.1 The Habitats catalogue

The entries were first broken down into five broad categories and then individual categories in single columns. These categories are Habitat type, Other map classifications/categories, Information, Region and Sources (described in 2.1.1.2-2.1.1.6), in addition to Data input identifier section (described in 2.1.1.1).

2.1.1.1 Data input identifier section

To identify the record and the record provider

- ID: the unique entry number for this record (filled by the catalogue administrators)
- No: the sequential number of the data entries starting from 1
- ID Partner: the acronym of the institution of the person providing the data
- Name: the name of the person providing the data
- E-mail: contact e-mail address of the person providing the data.

2.1.1.2 Habitat Type

- Category: drop-down list with options (a) 'Broad scale' or (b) 'Particular Habitat'. 'Broad scale' referring to large area, actual or predicted seabed habitat maps or geomorphology maps for regional, sub-regional or country area. 'Particular Habitat' if a specific habitat type with more detail in next column
- Type: only applicable if previous entry was 'Particular Habitat'. A drop-down list with options (a) 'Sublittoral soft', (b) 'Sublittoral hard', (c) 'Deep sea' (>200 m depth), and (d) 'Other' particular habitat
- Main feature: a drop-down list to specify habitat type, depending on category selected in the previous column. For 'Sublittoral soft': (a) *Posidonia*, (b) *Zostera*, (c) Other seagrass, (d) Other. For 'Sublittoral hard': (a) Maerl, (b) Coralligenous (including gorgonians), (c) Gorgonians, (d) Sponges, (e) *Cystoseira*/Macroalgal forests/beds, (f) Other. For 'Deep Sea' (a) Corals, (b) Sponges, (c) Mixed coral/sponge field, (d) Seamounts, (e) Hydrothermal vents, (f) Carbonate mounds, (g) Canyons, (h) Other. Not applicable for 'Broad scale' category.

2.1.1.3 Other map classifications/categories

- Sensitive/Vulnerable Marine Ecosystem (VME) Habitats: drop down list with options (a) Yes or (b) No. Any further information was added to the last column 'Comments'
- Area of Conservation Importance: drop down list with options (a) Yes or (b) No. Any further information was added to the last column 'Comments'
- Priority and Protected Species/Habitat: drop down list with options (a) Yes or (b) No. Any further information to be added to the last column 'Comments'
- Marine Protected Area (MPA): drop down list with options (a) Yes or (b) No. Any further information to be added to the last column 'Comments'.

2.1.1.4 Information

- Habitat/Features: free text, any additional relevant information for habitats, e.g. broad scale maps would include several maps on different features/types (EUNIS or similar classification level 3-4-5 maps, or sand-mud-gravel sediment type maps, or geological features e.g. canyons, seamounts, vents, as major focal points of conservation for restoration)
- Species included: free text, any important species, for example, included under wider Coralligenous grouping
- Depth: free text, the depth range of the habitats covered by the map
- Comments: free text, further details about the map source or findings of the paper/report, or any other useful information, e.g. human activities/impacts in the area.

2.1.1.5 Region

- Sea basins according to the MSFD Regions: a drop-down list of MSFD Regions with options (a) Baltic Sea, (b) North-East Atlantic, (c) Mediterranean Sea, (d) Black Sea, (e) Other Regional Sea. The latter category ('Other') refers to either sources at a global or European scale, or areas not included in the MSFD categories (such as Norwegian waters, or seafloor banks in the international waters of North-East Atlantic)
- MSFD sub-region: a drop-down list of MSFD sub-regions, applying only for North-East Atlantic and Mediterranean. Options for the North-East Atlantic are (a) Greater North Sea, including the Kattegat, and the English Channel, (b) Celtic Seas, (c) Bay of Biscay and the Iberian Coast, (d) Macaronesian biogeographic region (Azores, Madeira, Canary Islands). Options for the Mediterranean Sea are (a) Western Mediterranean Sea, (b) Adriatic Sea, (c) Ionian Sea and the Central Mediterranean Sea, (d) Aegean-Levantine Sea
- Other Subdivisions: free text for stating any further information or localised region e.g. ICES rectangles, GSA. A specification for non-MSFD regions (such as Norwegian waters, or seafloor banks in the international waters of NE Atlantic) also goes here, if 'Other regional sea' is selected in the first column.

2.1.1.6 Sources

- Source: a drop-down list with options (a) On-line resource/site, (b) Paper, (c) Report, (d) Conference paper, (e) Expert/Unpublished
- Type: a drop-down list with options (a) Map image (raster or printed image from a paper or on-line), (b) Map viewer (interactive image on-line), (c) Shapefile (possibility to individually download GIS format shapefiles)
- Reference: free text field, providing the full citation for the reference
- Reference Link: free text field, providing a web link to the reference
- Multiple Entries: a drop-down list with options (a) Yes or (b) No, depending on how many rows have been added per reference. 'Yes' indicates multiple entries for a single reference, as for example if a reference covers more than one regional area, or more than one habitat.

2.1.2 The Degraded habitats catalogue

The entries are broken down into eight broad categories and then individual categories in single columns. These categories are Habitat type, Other map classifications/categories, Status, Information, Region, Location of Site, Sources, Activities (incl. Endogenous pressures, exogenous pressures and Unspecified activities/pressures, described in 2.1.2.2-2.1.2.12), in addition to Data input identifier section (described in 2.1.2.1).

2.1.2.1 Data input identifier section

To identify the record and the record provider:

- ID: the unique entry number for this record (filled by the catalogue administrators)
- No.: the sequential number of the data entries starting from 1
- ID Partner: the acronym of the institution of the person providing the data
- Name: the name of the person providing the data
- E-mail: contact e-mail address of the person providing the data

2.1.2.2 Habitat

- Category: drop-down list with options (a) 'Broad scale' or (b) 'Particular Habitat'. 'Broad scale' referring to large area, actual or predicted seabed habitat maps or geomorphology maps for regional, sub-regional or country area. 'Particular Habitat' if a specific habitat type with more detail in next column
- Type: Type: only applicable if previous entry was 'Particular Habitat'. A drop-down list with options (a) 'Sublittoral soft', (b) 'Sublittoral hard', (c) 'Deep sea' (>200 m depth), and (d) 'Other' particular habitat
- Main Feature: a drop-down list to specify habitat type, depending on category selected in the previous column. For 'Sublittoral soft': (a) *Posidonia*, (b) *Zostera*, (c) Other seagrass, (d) Other. For 'Sublittoral hard': (a) Maerl, (b) Coralligenous (including gorgonians), (c) Gorgonians, (d) Sponges, (e) *Cystoseira*/Macroalgal forests/beds, (f) Other. For 'Deep Sea' (a) Corals, (b) Sponges, (c) Mixed coral/sponge field, (d) Seamounts, (e) Hydrothermal vents, (f) Carbonate mounds, (g) Canyons, (h) Other. Not applicable for 'Broad scale' category.

2.1.2.3 Other map classifications/categories

- Sensitive/ Vulnerable Marine Ecosystem (VME) Habitats: drop down list with options (a) Yes or (b) No. Any further information was added to the last column 'Comments'
- Area of Conservation Importance: drop down list with options (a) Yes or (b) No. Any further information was added to the last column 'Comments'
- Priority and Protected Species/Habitat. drop down list with options (a) Yes or (b) No. Any further information to be added to the last column 'Comments'
- Marine Protected Area (MPA). drop down list with options (a) Yes or (b) No. Any further information to be added to the last column 'Comments'

2.1.2.4 Status

- Status: free text, provide information on the status of the degraded habitat

- Level of Status: classified as (a) Assessed, i.e. status assessment under well-defined criteria using habitat-specific methodology, usually undertaken by expert groups under international organizations and/or commissions such as IUCN, HELCOM, OSPAR, Article 17 Habitats Directive, (b) Observed, i.e. when habitat degradation has been observed, by individual studies using various methodologies; e.g. as seen through the presence of negative impacts from various activities and pressures, decline in coverage, loss of habitat-forming key species, etc., (c) Modelled, e.g. when habitat degradation has been modelled in studies developing/applying cumulative impact indices, and (d) Assumed, e.g. habitat degradation not clearly stated but only assumed due to the presence of specific activities and pressures which potentially cause habitat degradation
- Extent of Decline: free text, information on the spatial extent of the decline, loss of habitat and current trend (stable/declining)
- Type of information on Extent of Decline: options are (a) Numerical/Quantitative, (b) Descriptive/Qualitative, or (c) No information
- Recovery potential: free text, on the potential for recovery, e.g. is there a good recovery potential if the activity is stopped or a pressure removed
- Type of Information on Recovery/Restoration Potential: classified as (a) Yes/Opinion, (b) Yes/Assessed, (c) No/Low/Poor, or (d) No information
- Suggested restoration actions: options are (a) Mitigation or removal of activities / Removal of impact, (b) Active restoration, (c) Combined, and (d) No information
- Main Activities: free text, information on activities operating at site (e.g. trawling, shipping)
- Type of activities: choice between Single or Multiple
- Main Pressures: free text, information on pressures impacting the site (e.g. 'Abrasion' from trawling or anchoring)
- Type of pressures: choice between single or multiple.

2.1.2.5 Information

- Habitat/Features: free text, any additional relevant information for habitats, e.g. broad scale maps would include several maps on different features (EUNIS or similar classification level 3-4-5 maps, or sand-mud-gravel sediment type maps, or geological features e.g. canyons, seamounts, vents, as major focal points of conservation for restoration)
- Species included: free text, any important species for example included under wider coralligenous grouping
- Depth: free text, the depth range of the habitats covered by the map

- Comments: free text, further details about the map source or findings of this paper/report, or any other useful information.

2.1.2.6 Region

- Sea basins according to the MSFD Regions: a drop-down list of MSFD Regions with options (a) Baltic Sea, (b) North-East Atlantic, (c) Mediterranean Sea, (d) Black Sea, (e) Other Regional Sea. The latter category ('other') refers to either sources at a global or European scale, or areas not included in the MSFD categories (such as Norwegian waters, or seafloor banks in the international waters of North-East Atlantic)
- MSFD sub-region: a drop-down list of MSFD sub-regions (applying only for North-East Atlantic and Mediterranean). Options for the North-East Atlantic are (a) Greater North Sea, including the Kattegat, and the English Channel, (b) Celtic Seas, (c) Bay of Biscay and the Iberian Coast, (d) Macaronesian biogeographic region (Azores, Madeira, Canary Islands). Options for the Mediterranean Sea are (a) Western Mediterranean Sea, (b) Adriatic Sea, (c) Ionian Sea and the Central Mediterranean Sea, (d) Aegean-Levantine Sea
- Other Subdivisions: free text for stating any further information or localised region e.g. ICES rectangles, GSA. A specification for non-MSFD regions (such as Norwegian waters, or seafloor banks in the international waters of NE Atlantic) also goes here, if 'Other regional sea' is selected in the first column.

2.1.2.7 Location of site

- Longitude
- Latitude
- Depth

2.1.2.8 Sources

- Source: a drop-down list with options (a) On-line resource/site, (b) Paper, (c) Report, (d) Conference paper, (e) Expert/Unpublished
- Type: a drop-down list with options (a) Map image (raster or printed image from a paper or on-line), (b) Map viewer (interactive image on-line), (c) Shapefile (possibility to individually download GIS format shapefiles)
- Reference: free text field, providing the full citation for the reference
- Reference Link: free text field, providing a web link to the reference

- Multiple Entries: a drop-down list with options (a) Yes or (b) No, depending on how many rows have been added per reference. 'Yes' indicates multiple entries for a single reference, as for example if a reference covers more than one regional area, or more than one habitat.

2.1.2.9 Activities/pressures

For all activities potentially causing habitat degradation as reported by the authors in each paper/report/reference: 1-value if the activity is present (activity list and definitions taken from Smith et al. 2016):

- 13 columns relating to activities (see also Table 1 in MERCES Report D1.2, Smith et al. 2017: Current marine pressures and mechanisms driving changes in marine habitats)
- Activities comments: free text, any extra information on specific activities.

Endogenous (manageable within a local system) pressures

For all pressures potentially causing habitat degradation as shown in each paper/report/reference data: 1-value if the pressure is present (endogenous pressures list and definitions taken from Smith et al. 2016):

- 26 columns relating to endogenous pressures (see also Table 2a in MERCES Report D1.2, Smith et al. 2017: Current marine pressures and mechanisms driving changes in marine habitats)
- Endogenous Pressures Comments: free text, any extra information.

Exogenous (unmanageable with local measures) pressures

For all pressures potentially causing habitat degradation according to the paper/report/reference data and matching the definitions provided: 1-value if the pressure is present (exogenous pressures list taken from Smith et al. 2016):

- 7 columns relating to exogenous pressures (see Table 2b in MERCES Report D1.2, Smith et al. 2017: Current marine pressures and mechanisms driving changes in marine habitats)
- Exogenous Pressures comments: free text, any extra information.

Unspecified activities/pressures

For presence (1-value) of multiple unspecified activities/pressures potentially causing habitat degradation according to the reference data. 5 columns:

- Multiple unspecified activities
- Unspecified activities leading to eutrophication
- Unspecified activities causing pollution
- Multiple unspecified pressures
- Climate change

2.2. Catalogue analysis

Once the catalogues had been collated and checked, a systematic review was undertaken to highlight the different data categories and ranges over, for example, the source of the data, the regional distribution of the entries etc.

2.3. Case Study Habitats Features/Properties

Case study habitats were selected by the MERCES WP1 group in order to represent the MERCES focal habitat types (Shallow soft bottom habitats, Shallow hard bottom habitats and Deep-sea Habitats), in which restoration effort is taking place. Most of the MERCES restoration efforts are active restoration method, ("re-introduction", according to Elliot et al. 2007 and as illustrated in Figure 1.3). Case study habitats were reviewed for both WP1 Task 1.1. (key and degraded habitats) and Task 1.2. (pressures and activities). The case study habitats selected are as follows:

- Shallow soft bottom habitats:
    - Mediterranean, Baltic and North Atlantic seagrass meadows
- Shallow hard bottom habitats:
    - North-East Atlantic kelp forests, i.e. the two forest building species in Norway, *Laminaria hyperborea* and *Saccharina latissima*
    - Mediterranean Sea macroalgal forests, shallow and deep *Cystoseira*
    - Mediterranean coralligenous assemblages
- Deep-sea habitats:
    - Coral gardens in the Azores
    - Deep-sea bottom communities in the Mediterranean basin and Central-Northern Atlantic

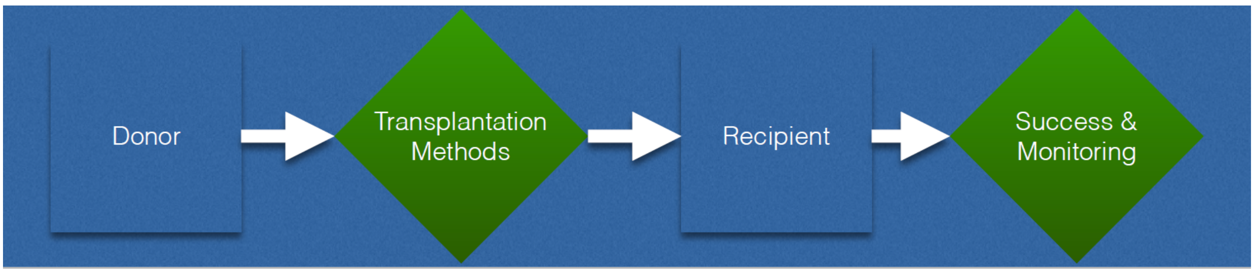


Figure 1.3. Workflow of the active restoration method ("re-introduction", according to Elliot et al. 2007) that applies to the project study cases. Donor is the source area, where organisms are taken. Recipient is the area that needs restoration, where organisms are transplanted. The donor area will then be further monitored to ensure the success of restoration.

Following a workshop of WP1 participants the following key important, but generic features were identified in order to systematically assess the factors that are relevant to restoration and thereby the chances of recovery (recovery potential): Dynamics (such as growth rate and longevity), Connectivity (such as dispersal and gene flow), Spatial distribution, Vulnerability/Fragility, Structural complexity (e.g. 3D complexity) and Diversity (including taxonomic, functional and genetic diversity, and diversity of associated species). For each case study habitat, a table (Table 3.2-3.9) was constructed relating the above features to the potential for restoration.

3. Results

3.1. The Habitats catalogue

Of the 577 entries of the two catalogues (Annex 4), maps depicting the distribution of habitats within European Seas accounted for 65%. The following sections provide an overview of the main outcomes and findings, highlighting properties of the focal habitats.

3.1.1. Habitats Maps: Category Groups and Categories

Overall, the Habitats catalogue consists of 376 entries, including entries from all major European seas and global maps.

3.1.1.1 Sources of information

The majority of entries (218: 58%) came from the grey literature, and consisted of reports (121: 56%), online resources/websites (84: 39%) and conference papers (13: 6%), with a further 146 (39%) coming from peer-reviewed papers and the remainder coming from expert/unpublished documents (11: 3%) and a single book chapter (Figure 3.1A). The majority of sources provided only images of maps (295: 78%) while shapefiles (directly useable in GIS applications) and map viewers (on-line interactive maps) accounted for small percentages (31: 8% and 50: 13%, respectively) (Figure 3.1B).

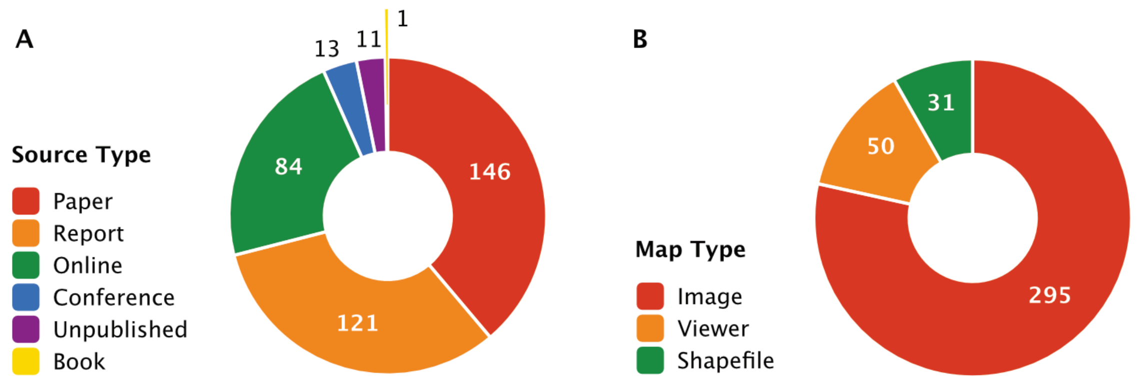


Figure 3.1. Number of existing habitat map entries by (A) source type and (B) map type.

3.1.1.2 Breakdown of entries by region and habitat type

Entries from the Mediterranean Sea comprise most of this catalogue's entries (162: 43%), followed by those from the North-East Atlantic Ocean (124: 33%), the Baltic Sea (43 entries: 11%) and a small percentage (11: 3%) from the Black Sea (Figure 3.2A). Moreover, 36 entries (10%) concerned non-European Regional Seas and/or global maps (Other).

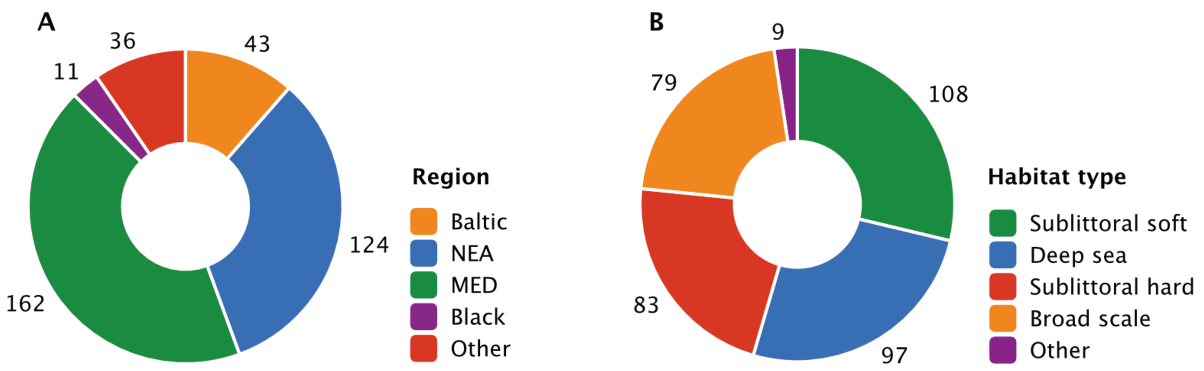


Figure 3.2. Habitat map entries by (A) regions and (B) habitat type. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (A) Non-European Regional Seas or Global maps, (B) Other types of habitats).

A high percentage of the entries relate to a particular focal habitat (297: 79%). Sublittoral soft and deep-sea habitats dominated (108: 29% and 97: 26% entries, respectively), followed by sublittoral hard and broad scale maps (83: 22% and 79: 21%, respectively) while a small number related to other habitats (9: 2%).

3.1.1.3 Breakdown of entries by focal habitat

For all major habitat types, the majority of entries are from the Mediterranean Sea, followed by the North-East Atlantic and the Baltic Seas, except for the deep-sea habitat, from where there were no deep-sea habitat map entries (Figure 3.3).

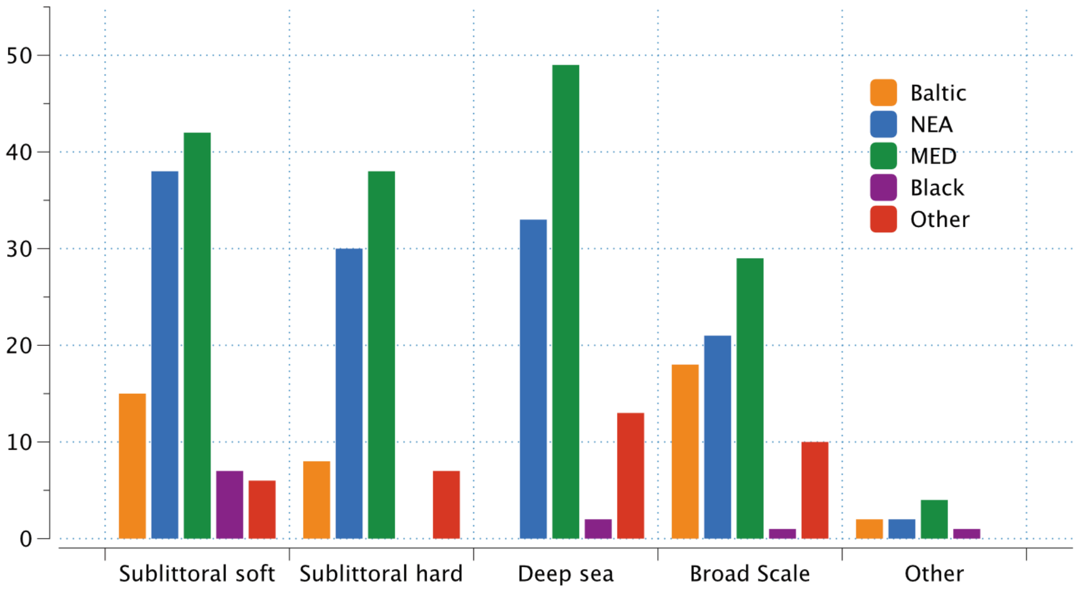


Figure 3.3. Habitat map entries by major habitat type and region. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)).

Deep-sea bottom communities

Of the deep-sea habitats considered in the study, the majority of entries relate to coral gardens, canyons, seamounts and hydrothermal vents (Figure 3.4A) and are mainly reported from the Mediterranean Sea and the North-East Atlantic Ocean (Figure 3.5). Within the Mediterranean Sea, the number of deep sea habitats reported decreased from west to east (Figure 3.4B) and within the North-East Atlantic the majority of the entries are from the Macaronesia region (Azores, Madeira, Canary Islands), the Celtic Sea, the Bay of Biscay and the Iberian Coast (Figure 3.4C). In addition, a number of entries (15 in total, Figure 3.4A) were found for other deep-sea habitats, such as mud mounds, mud volcanoes and deep-sea basins and open slopes, most of which are located in the Mediterranean Sea (Figure 3.5).

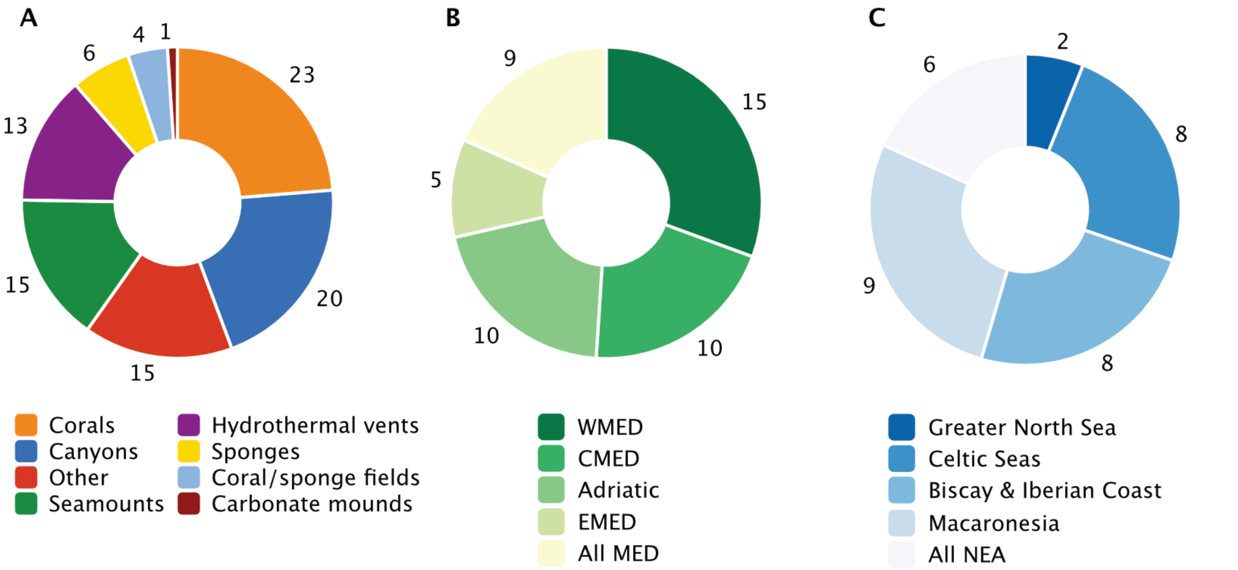


Figure 3.4. Deep-sea habitat map entries by (A) different deep-sea habitat types, (B) different sub-regions of the Mediterranean, and by (C) the different sub-regions of the North-East Atlantic Ocean. (WMED: Western Mediterranean; CMED: Ionian Sea and the Central Mediterranean; Adriatic: Adriatic Sea; EMED: Aegean-Levantine Sea; All MED: All Mediterranean regions; All NEA: All North-East Atlantic Ocean regions; Greater North Sea: Greater North Sea, including the Kattegat and the English Channel; Macaronesia: Macaronesian biogeographic region (Azores, Madeira, Canary Islands).

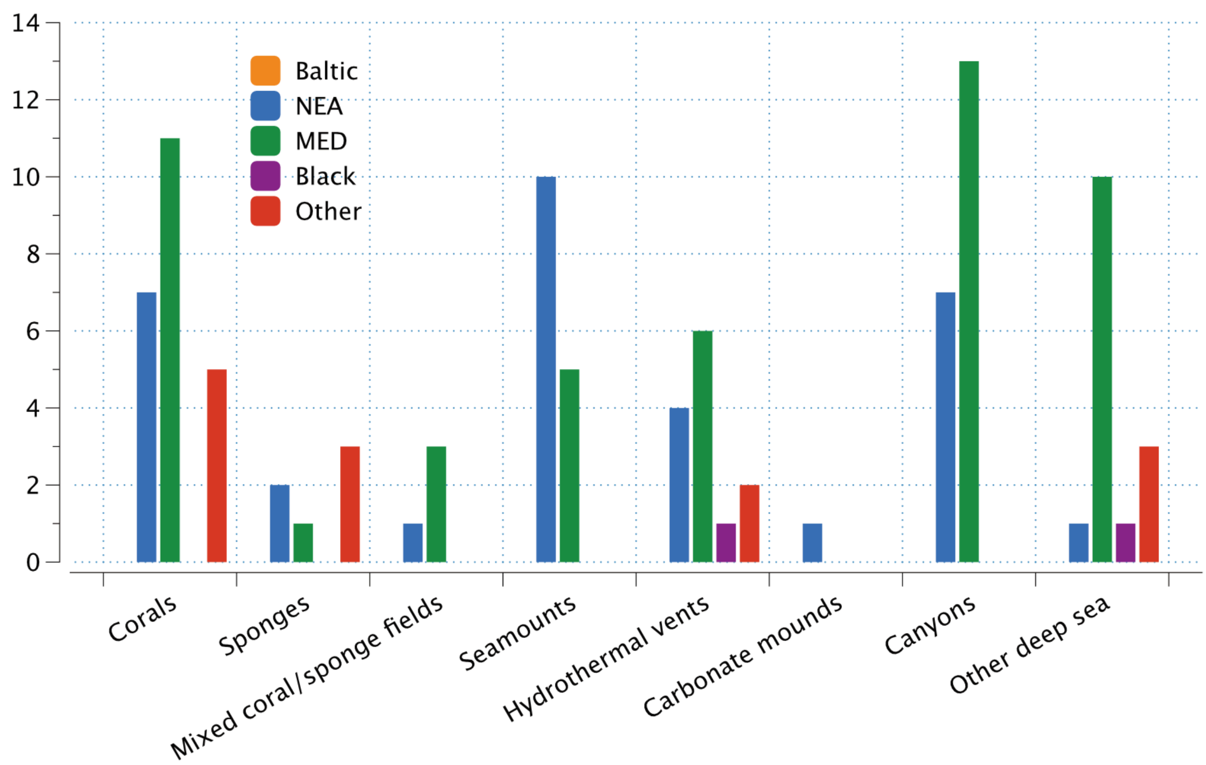


Figure 3.5. Deep-sea habitat map entries by habitat type and region. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)).

Sublittoral soft substrate habitats

The majority of entries for sublittoral soft substrate habitats are for *Zostera* spp. meadows, followed by *Posidonia oceanica* meadows and then other seagrass meadows (e.g. *Cymodocea nodosa* and *Ruppia maritima*) (Figure 3.6A). The majority of Mediterranean entries report seagrass distributions for the whole Mediterranean region rather than any particular sub-region (Figure 3.6B), while in the Atlantic the majority are from the Greater North Sea (including the Kattegat and the English Channel) (Figure 3.6C).

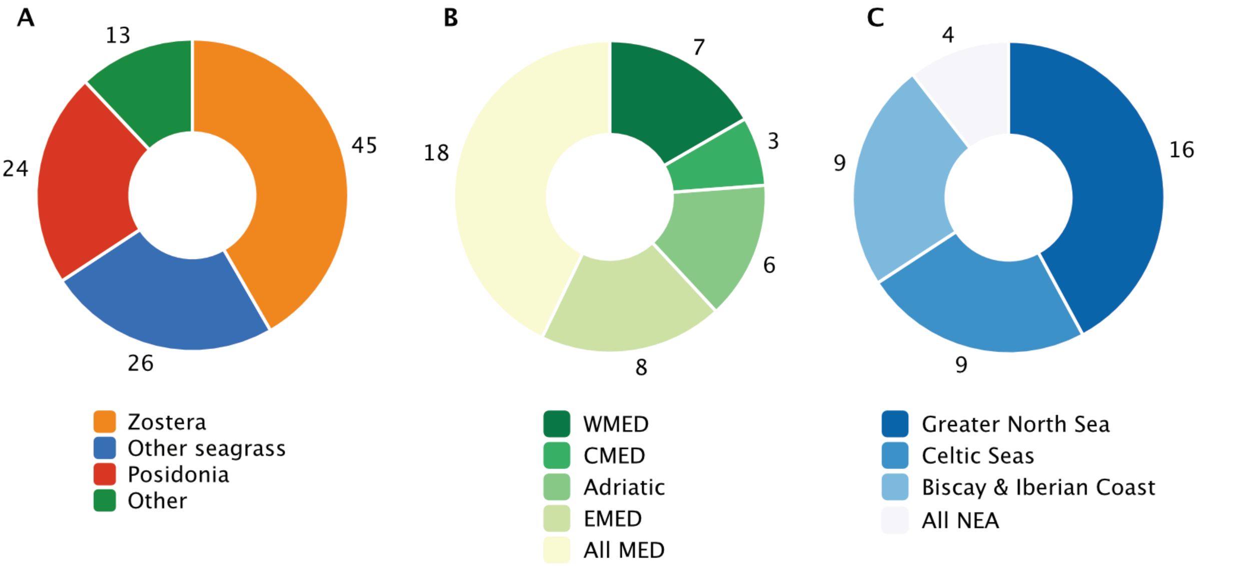


Figure 3.6. Sublittoral soft substrate habitat map entries by (A) different habitat types, (B) different sub-regions of the Mediterranean, and by (C) the different sub-regions of the North-East Atlantic Ocean. (WMED: Western Mediterranean; CMED: Ionian Sea and the Central Mediterranean; Adriatic: Adriatic Sea; EMED: Aegean-Levantine Sea; All MED: All Mediterranean regions; All NEA: All North-East Atlantic Ocean regions; Greater North Sea: Greater North Sea, including the Kattegat and the English Channel; Macaronesia: Macaronesian biogeographic region (Azores, Madeira, Canary Islands).

Most *Zostera* meadows entries are from the North-East Atlantic (24) while a few entries were identified for the Baltic, the Mediterranean and the Black seas (9, 6 and 5 respectively) (Figure 3.7). Other types of seagrass meadows, such as *Cymodocea* and *Ruppia* beds, were recorded mostly in the Mediterranean Sea and the North-East Atlantic Ocean, whilst a few entries were from wider European regions or global distribution. As a species endemic to the Mediterranean Sea, entries for *Posidonia oceanica* meadows (24) are restricted only in the Mediterranean (Figure 3.7).

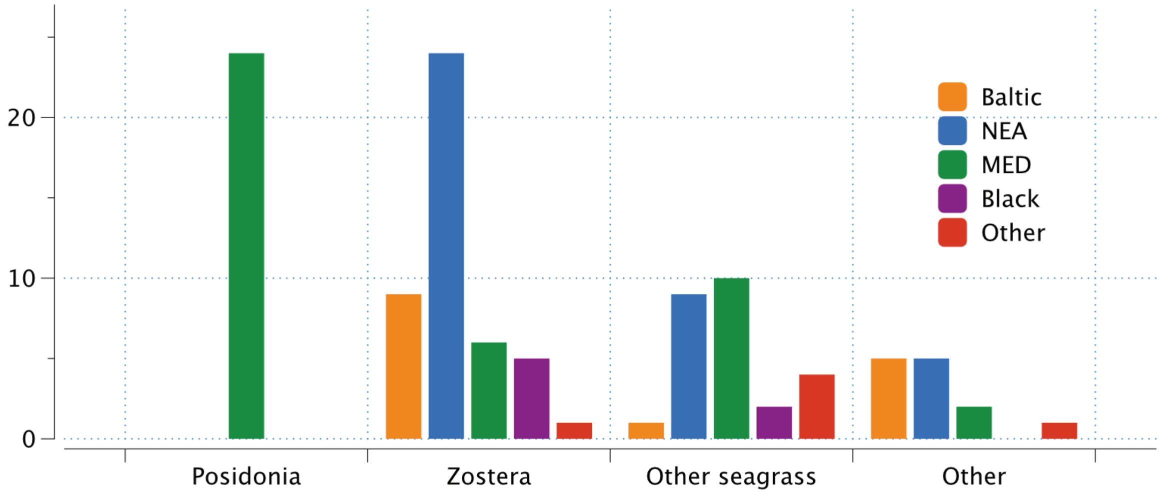


Figure 3.7. Sublittoral soft substrate habitat map entries by habitat type and region. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)).

Sublittoral hard substrate habitats

In relation to sublittoral hard substrate, *Cystoseira*/Macroalgal forests/beds had the highest number of entries (20), followed by maerl beds (17) and coralligenous assemblages (10) (Figure 3.8A). Within the Mediterranean Sea, the majority of entries are for the whole sea (11), with high numbers also found in the Western and the Eastern basins (10 and 9 respectively) (Figures 3.8B). Within the North-East Atlantic, the majority are from the Greater North Sea, including the Kattegat and the English Channel and the Celtic Seas (Figures 3.8C). For coralligenous assemblages, entries (10) are restricted in the Mediterranean Sea (Figure 3.9). For *Cystoseira*/Macroalgal forests the majority of entries are from the Mediterranean (12), while maerl beds were primarily recorded in the North-East Atlantic (10 entries) (Figure 3.9).

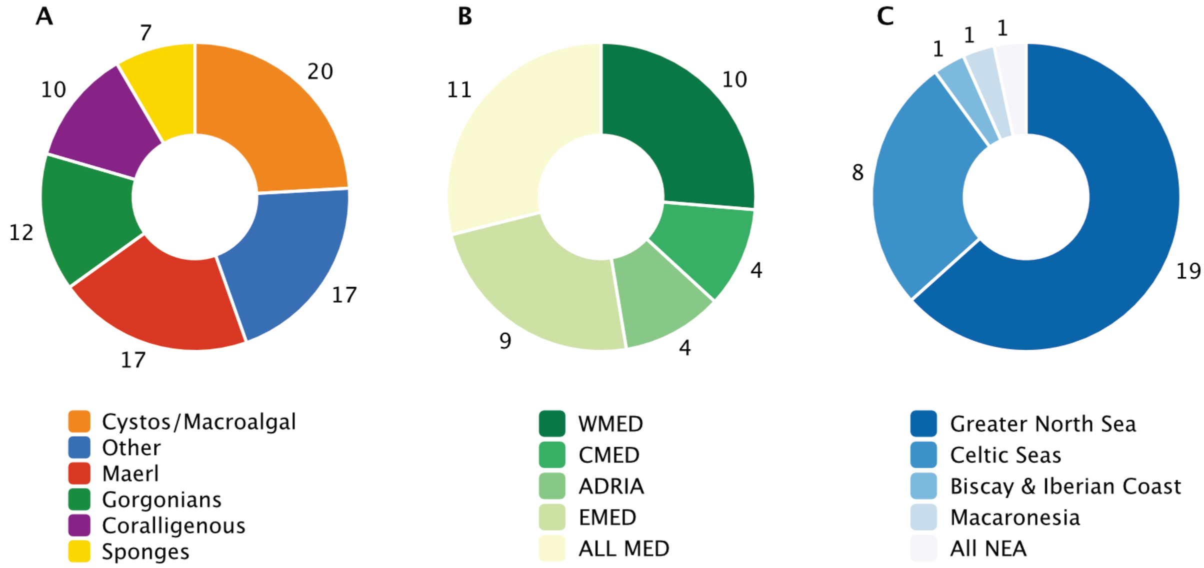


Figure 3.8. Sublittoral hard substrate habitat map entries by (A) different habitat types, (B) different sub-regions of the Mediterranean, and by (C) different sub-regions of the North-East Atlantic Ocean. (WMED: Western Mediterranean; CMED: Ionian Sea and the Central Mediterranean; Adriatic: Adriatic Sea; EMED: Aegean-Levantine Sea; All MED: All Mediterranean regions; All NEA: All North-East Atlantic Ocean regions; Greater North Sea: Greater North Sea, including the Kattegat and the English Channel; Macaronesia: Macaronesian biogeographic region (Azores, Madeira, Canary Islands).

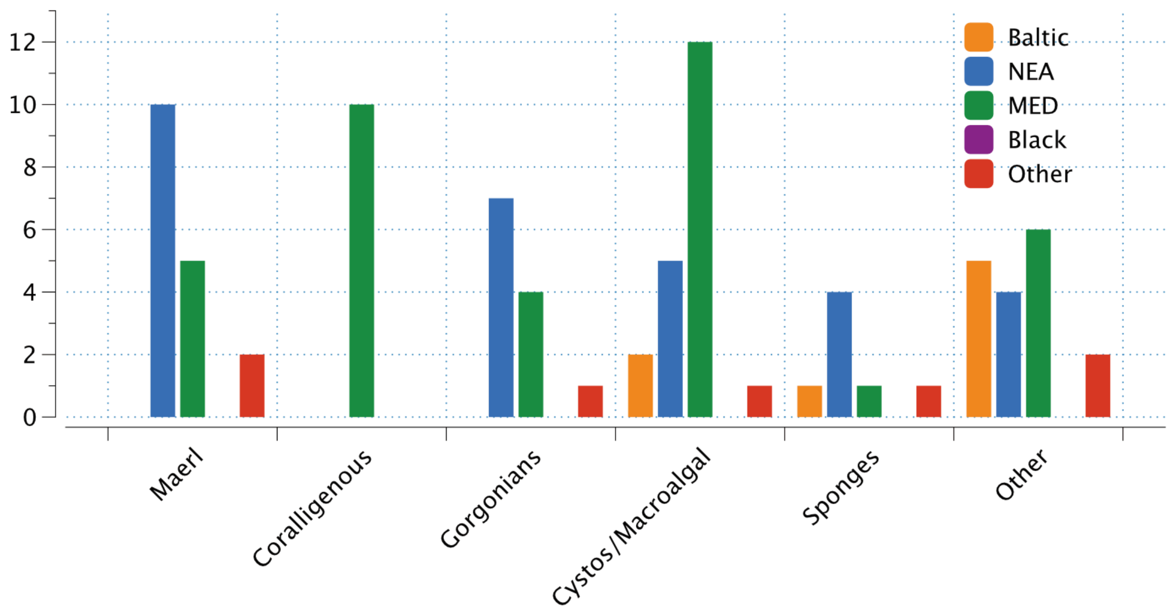


Figure 3.9. Sublittoral hard substrate habitat map entries by habitat type and region. (Cystos/Macroalgal: *Cystoseira*/Macroalgal forests/beds; Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)).

3.1.1.4 Areas of Importance

There is a relatively high number of Sensitive Habitats (SHs)/Vulnerable Marine Ecosystems (VMEs) (STEC 2006, FAO 2009) entries within the catalogue (68%), the majority of which are located in the Mediterranean Sea and the North-East Atlantic Ocean (Figure 3.10). The habitats include seagrass meadows, coral gardens, sponge aggregations, maerl beds, *Cystoseira*/Macroalgal forests/beds, areas with gorgonian forests and several deep-sea habitats such as seamounts, canyons, coral gardens and hydrothermal vents. Whilst in the Baltic Sea, the entries are mainly for *Zostera* and other seagrass meadows, the majority of entries within the Black Sea are for *Zostera* meadows. At the global scale, the catalogue includes entries of sensitive seagrass meadows, maerl beds, deep-sea coral gardens and hydrothermal vent habitats, while for the Norwegian marine areas, the entries are mostly for deep sea habitats (deep-sea corals gardens and sponge aggregations), along with gorgonian forests, maerl beds and *Zostera* meadows.

Similar to the VMEs, there is a relatively high percentage of Priority and Protected Species/Habitats entries (68%), the majority of which are found in the Mediterranean and the North-East Atlantic (Figure 3.10). In the Mediterranean, these include several vegetated habitats (*Posidonia/Zostera* meadows and macroalgal forests), deep-sea habitats (hydrothermal vents and coral gardens) and sublittoral hard substrate habitats (coralligenous assemblages, gorgonian forests and maerl beds). Whilst within the North-East Atlantic the entries are principally for *Zostera* meadows, several sublittoral hard substrate habitats (e.g. maerl beds, sponge aggregations, gorgonian forests) and deep-sea habitats (seamounts, hydrothermal vents and coral gardens). Within the Black Sea the entries are for *Zostera* meadows, areas of fluid flow, mud mounds and landslides and within the Baltic they are mainly for *Zostera* meadows.

There are 95 entries (25%) of areas of conservation importance, the majority of which occur in the Mediterranean Sea (Figure 3.10). This includes *Posidonia* meadows, *Cystoseira* forests, coralligenous assemblages, maerl beds, and deep-sea canyons and coral gardens. The catalogue also contains *Zostera* meadows in the Baltic, deep-sea canyons and seamounts in North-East Atlantic and several types of seagrass meadows, sublittoral hard substrate (coralligenous assemblages, maerl beds and sponge aggregations) and deep-sea (coral gardens and sponge aggregations) habitats in the Norwegian and Barents seas.

A low percentage of the maps relate to Marine Protected Areas (MPAs) (12%, 45 entries) (Figure 3.10). Mapped MPAs in the NEA include the following habitats: kelp forests, *Zostera* meadows and deep-sea canyons, seamounts and hydrothermal vents. Likewise, several vegetated (e.g. seagrass meadows, *Cystoseira* beds), coralligenous assemblages and deep-sea habitats (coral gardens and canyons) have been mapped within Mediterranean MPAs. Table 3.1 shows the number of focal habitats per regional sea that intersect with Vulnerable Marine Ecosystems (VMEs) and Marine Protected Areas (MPAs). This table is the product of overlaying VME and MPA boundaries (available at UNEP-WCMC) on top of the habitats of interest and calculate the amount that are in a VME/MPA and the amount that are not, per regional sea. This shows an indication of the (very different) extent to which these habitats are 'found' in conservation areas, irrespectively of the fact that although these areas are spatially defined they are not yet, in most cases, mapped in terms of habitat features or habitat degradation.

Table 3.1. The number of point locations and percentage of each focal habitat that intersect with Vulnerable Marine Ecosystems (VMEs) and Marine Protected Areas (MPAs) per regional sea. It is important to note that Norway does not use the classification "VME" and therefore does not have any numbers for this class. No data were available for sponge aggregations

Region	Area of interest	Seagrass meadows	Cold water corals	Maerl beds	Seamounts	Canyons	Hydro-thermal vents
Norway (North, Norwegian, Barents Sea)	MPA	42 25 %	1267 31 %			10 77 %	
	VME						
	Whole Area	168	4057			13	
Black Sea	MPA	13 18 %					
	VME						
	Whole Area	73					
Baltic Sea	MPA	1383 55 %	40 52 %			2 100 %	
	VME						
	Whole Area	2504	77			2	
Mediterranean Sea	MPA	657 45 %	189 22 %	228129 18 %	11 6 %	4 20 %	4 27 %
	VME		94 11 %	1228 0.01 %			
	Whole Area	1471	850	1263661	180	20	15
NE Atlantic	MPA	3201 68 %	2988 26 %		27 2 %	19 35 %	5 14 %
	VME		1978 17 %		110 8 %	1 2 %	
	Whole Area	4680	11635		1287	55	36

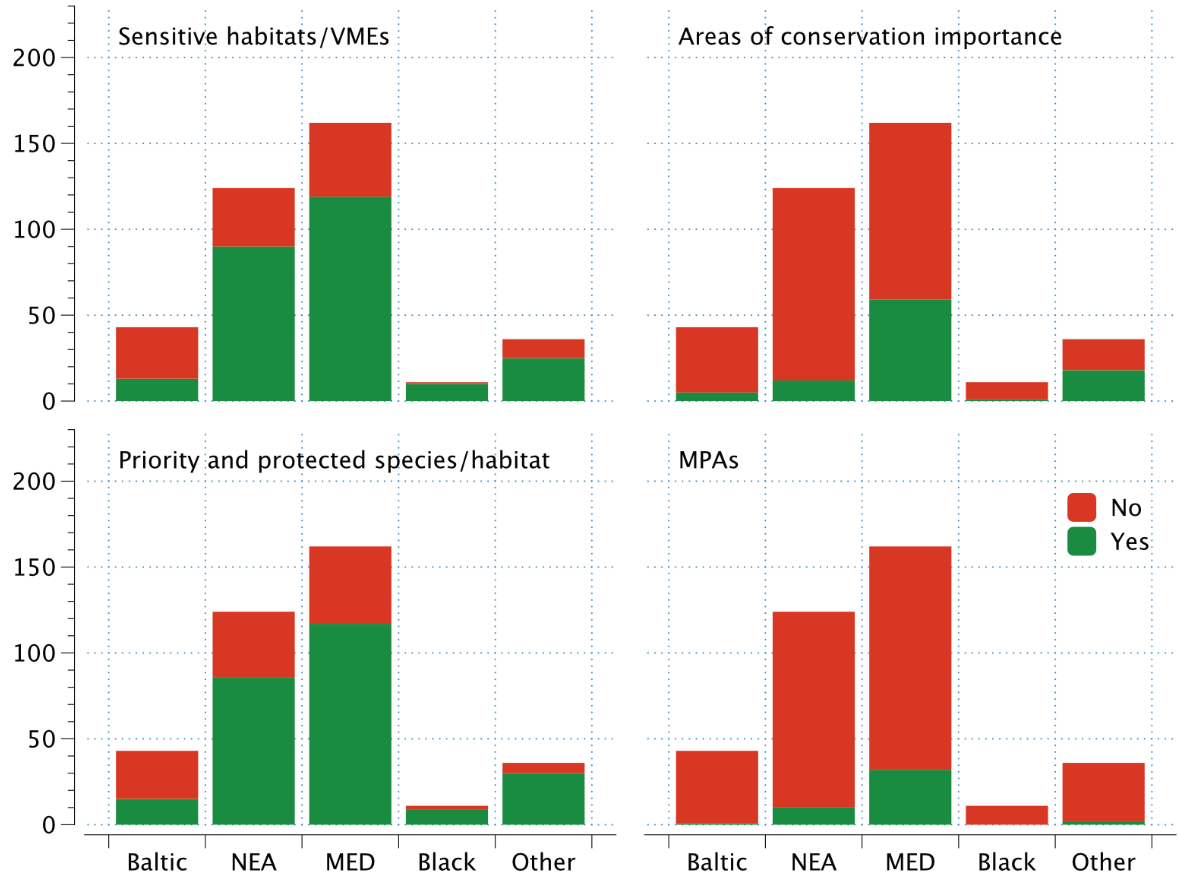


Figure 3.10. Habitat map entries by region with respect to Sensitive Habitats (SH) /Vulnerable Marine Ecosystems - VMEs, Areas of Conservation Importance, Priority and Protected Species/Habitats, and Marine Protected Areas (MPAs). (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)).

3.2. The MERCES Degraded habitats catalogue

Of the 577 entries of the two catalogues, 35% relate to maps of degraded habitats in European seas. The following sections provide an overview of the main outcomes and findings, highlighting properties of degraded habitats and considerations on their extent, stability, sensitivity and recovery potential.

3.2.1 Degraded Maps: Category groups and categories

The Degraded habitats catalogue includes 201 entries, containing maps from all major European seas, the Norwegian coast, as well as global scale maps (all grouped under the generic category "Other").

3.2.1.1 Information sources

In contrast to the Habitats catalogue, the majority of the Degraded habitat entries were derived from papers (134: 67%), a lower percentage from reports (54: 27%), and a few from online resources (11: 5%) (Figure 3.11A). The vast majority relate to map images (188: 94%) while shapefiles (directly useable in

GIS applications) and map viewers (on-line interactive maps) accounted for 6% of the entries (Figure 3.11B).

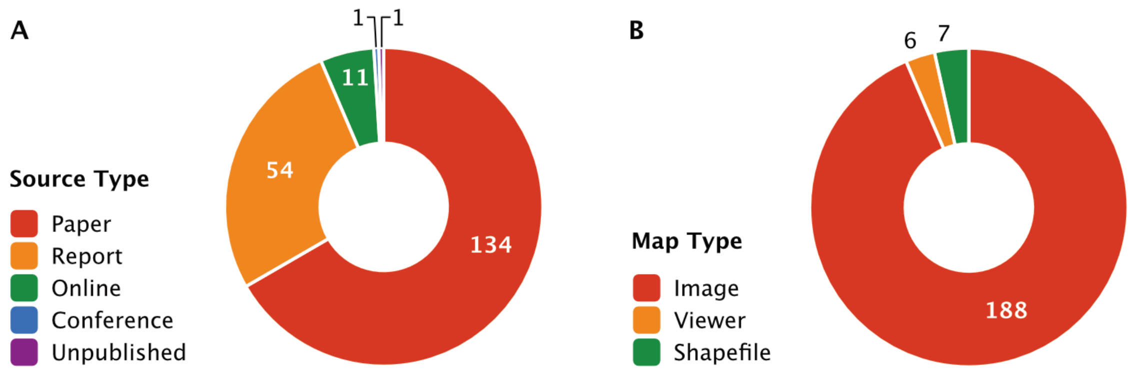


Figure 3.11. Number of degraded habitat map resource entries by (A) source type and (B) map type.

3.2.1.2 Distribution of Degraded habitat maps

The majority of entries are for the Mediterranean Sea (93: 46%), followed by the North-East Atlantic Ocean (60: 30%) the Baltic Sea (32: 16%) and a small percentage (2%) from the Black Sea (Figure 3.12A).

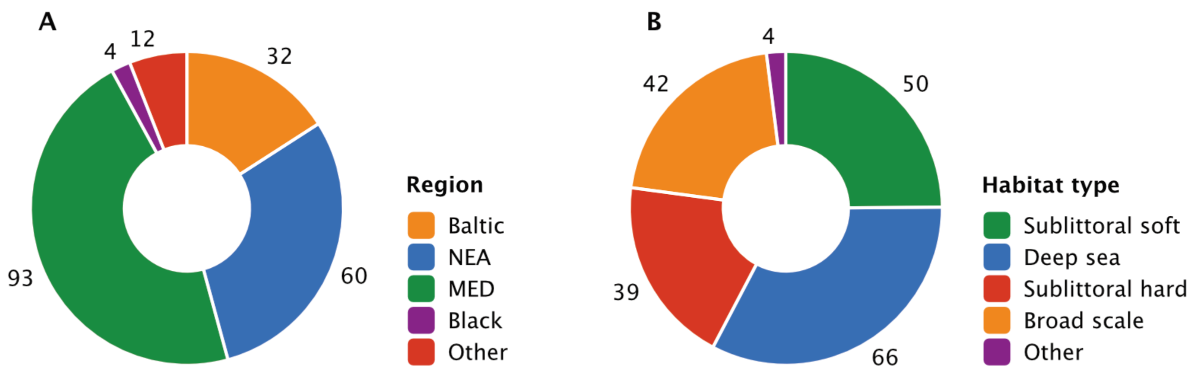


Figure 3.12. Degraded habitat map entries by (A) region and (B) habitat type. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (A) Non-European Regional Seas or Global maps, (B) Other types of habitats).

A high percentage of the entries relate to smaller-scale, specific habitat types (79%); of these, sublittoral habitats dominate (66: 33% and 50: 25% entries for hard and soft substrates, respectively) followed by deep-sea habitats (39: 19%) (Figure 3.12B).

3.2.1.3 Degraded Habitat Map Resources by Key Habitat

For sublittoral habitats, the highest number of entries are from the Mediterranean, followed by the North-

East Atlantic Ocean and the Baltic Sea. Within the deep sea, the majority of entries come from the North-East Atlantic Ocean (Figure 3.13). Most map resources of degraded habitats in the Baltic are provided on a broad scale, with some information presented for the sublittoral habitat types (13 entries in total).

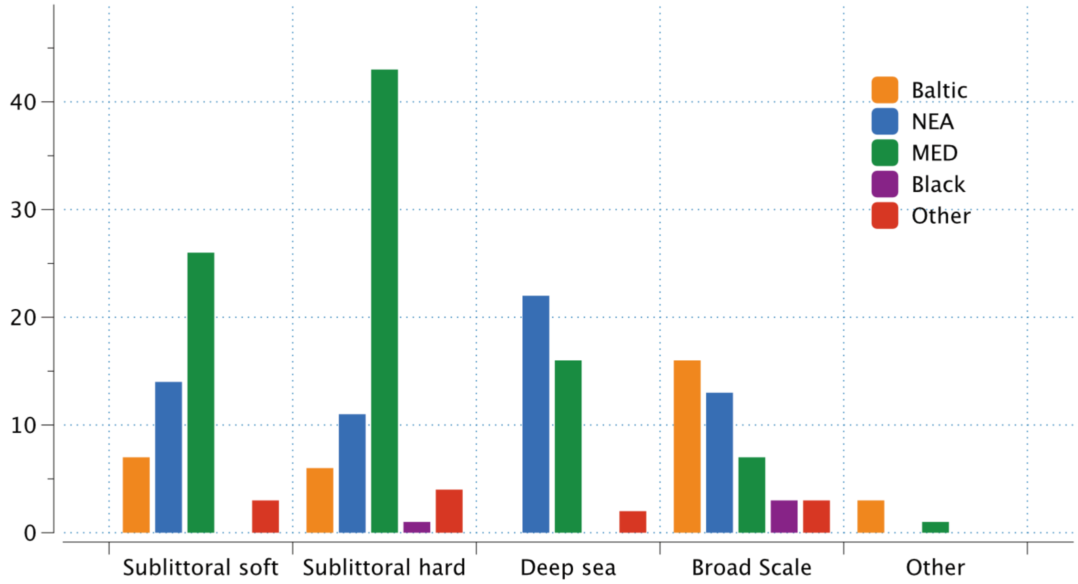


Figure 3.13. Degraded habitat map entries by region. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)).

Deep-sea habitats

Of the various types of deep-sea habitats considered, most entries are for coral gardens and canyon habitats (16 and 9 respectively; Figure 3.14A), which were mainly reported from the North-East Atlantic Ocean and the Mediterranean Sea (Figure 3.15). Similar to the patterns seen in the Habitats catalogue there is an eastward declining trend of information within the Mediterranean (Figure 3.14B). Within the North-East Atlantic, the majority of deep sea entries are from the Celtic Seas, the Bay of Biscay and the Iberian Coast (Figure 3.14C). Within the North-East Atlantic all habitat types are present, however, this is not the case for the other regions considered in the analysis; in particular, within the Baltic and Black seas where no entries are present (Figure 3.15).

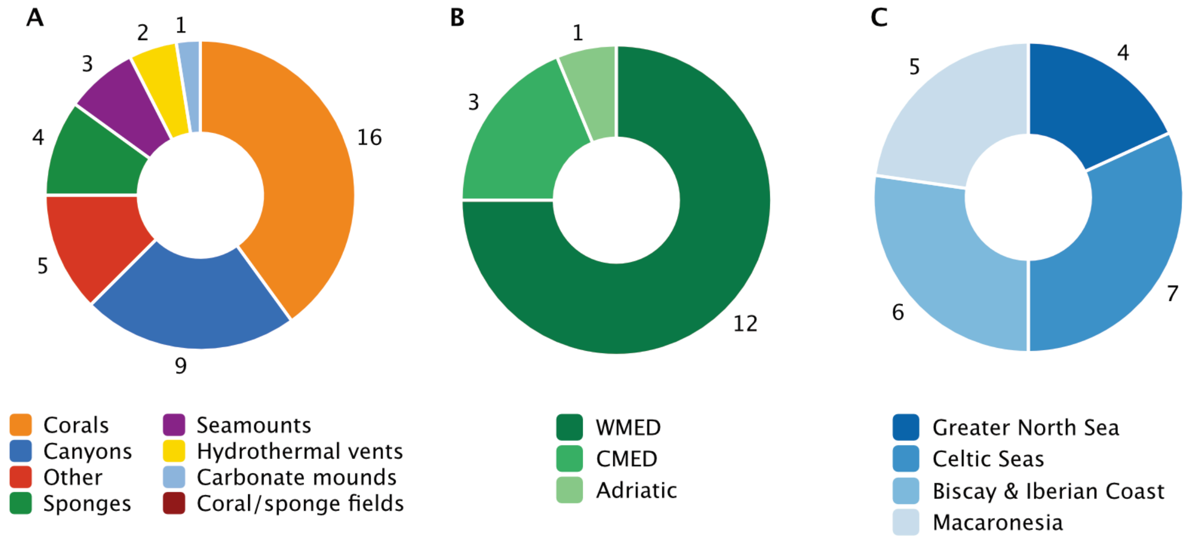


Figure 3.14. Degraded deep-sea habitat map entries by (A) different deep-sea habitat types, (B) different sub-regions of the Mediterranean, and by (C) different sub-regions of the North-East Atlantic. (WMED: Western Mediterranean; CMED: Ionian Sea and the Central Mediterranean; Adriatic: Adriatic Sea; Greater North Sea, including the Kattegat and the English Channel; Macaronesia: Macaronesian biogeographic region (Azores, Madeira, Canary Islands).

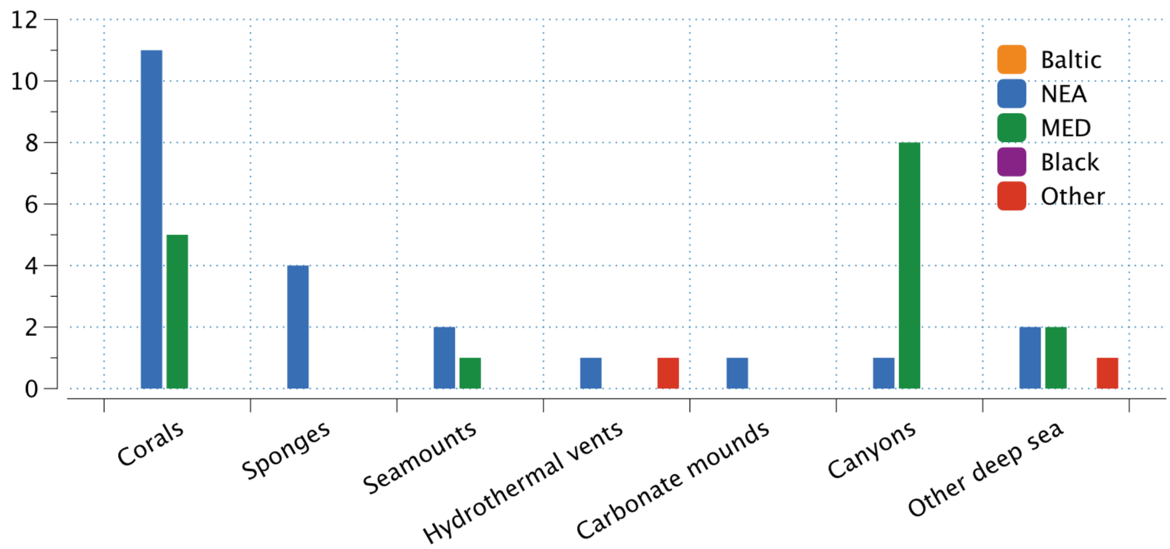


Figure 3.15. Degraded deep-sea habitat map entries by habitat type and region. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)).

Sublittoral soft substrate habitats

The majority of entries relate to degraded *Zostera* and *Posidonia oceanica* meadows (Figure 3.16A). Within the Mediterranean region, the majority of entries are from the Western Mediterranean (12 entries) and the whole Mediterranean Sea (7 entries) (Figure 3.16B), whilst in the Atlantic, the majority are from the Greater North Sea (12 entries) and to a lesser extent (2 entries) the Bay of Biscay and the Iberian Coast (Figure 3.16C).

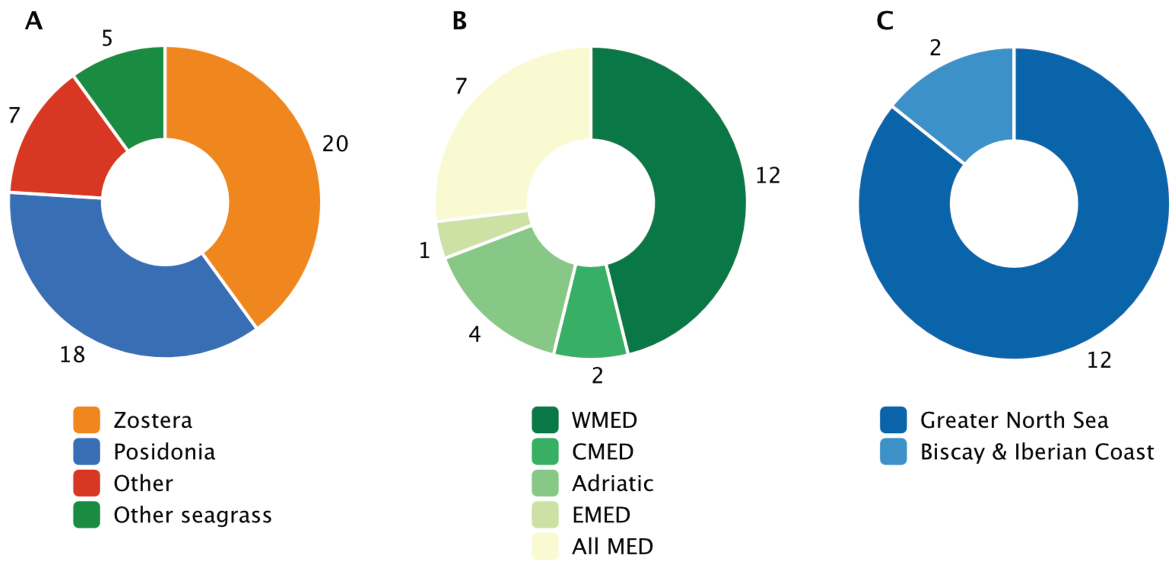


Figure 3.16. Degraded Sublittoral soft substrate habitat maps by (A) different habitat types, (B) different sub-regions of the Mediterranean, and by (C) different sub-regions of the North-East Atlantic Ocean. (WMED: Western Mediterranean; CMED: Ionian Sea and the Central Mediterranean; Adriatic: Adriatic Sea; EMED: Aegean-Levantine Sea; All MED: All Mediterranean regions; Greater North Sea: Greater North Sea, including the Kattegat and the English Channel).

The degraded habitat entries for *Posidonia oceanica* meadows are, as expected, restricted to the Mediterranean Sea (18 entries) (Figure 3.17). Degraded *Zostera* spp. meadows have been mapped in all major regions of the catalogue except in the Black Sea, for which there are no entries of degraded sublittoral soft substrate habitat. *Cymodocea nodosa* meadows and soft sediments with algae, sea-pens and other benthic communities have also been mapped and reported as “Other” degraded sublittoral soft substrate habitats in the Mediterranean and the North-East Atlantic Ocean (Figure 3.17).

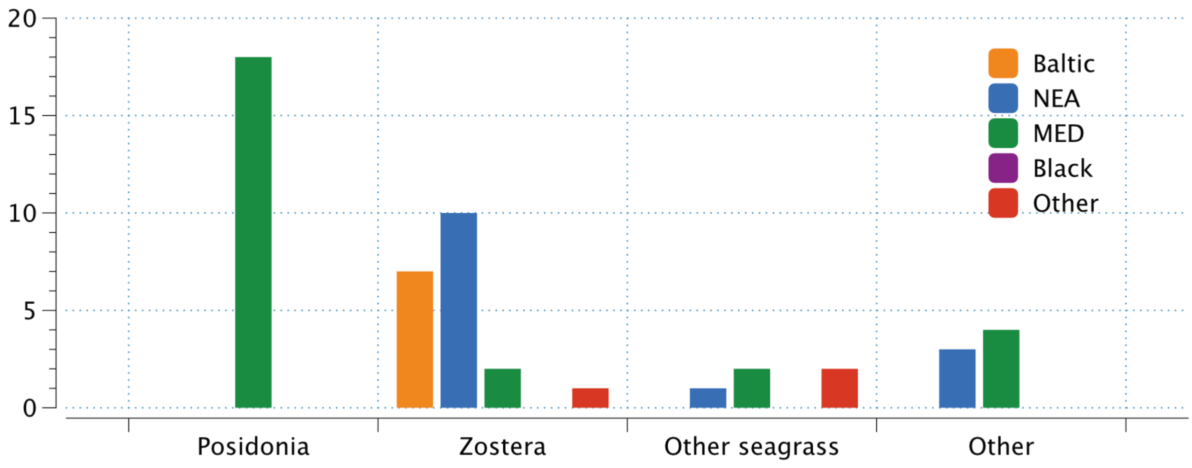


Figure 3.17. Degraded sublittoral soft substrate habitat map entries by habitat types and region. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)).

Sublittoral hard substrate habitats

Almost half of the sublittoral hard substrate entries are *Cystoseira*/Macroalgal forests/beds (31: 48%) (Figure 3.18A). The next most represented groups are gorgonian forests and coralligenous assemblages with 7 entries each (11%) and a further 20% (13 entries) from other sublittoral hard substrate habitats such as reefs, mussel/oyster beds and mixed hard and soft substrates dominated by anemones or stone corals (Figure 3.18A). *Cystoseira*/Macroalgal forests/beds and gorgonian forest entries are mostly from the Mediterranean (22 and 6 entries, respectively), coralligenous assemblage map entries are restricted in the Mediterranean (7 entries) while degraded maerl beds have been mapped only in the North-East Atlantic (4 entries) (Figure 3.19). Within the Mediterranean, 56% of the entries are in the Western basin and 19% across the whole region (Figure 3.18B). Within the North-East Atlantic, the few entries of this habitat type (11) are mainly from the Greater North Sea, including the Kattegat and the English Channel (64%) (Figure 3.18C).

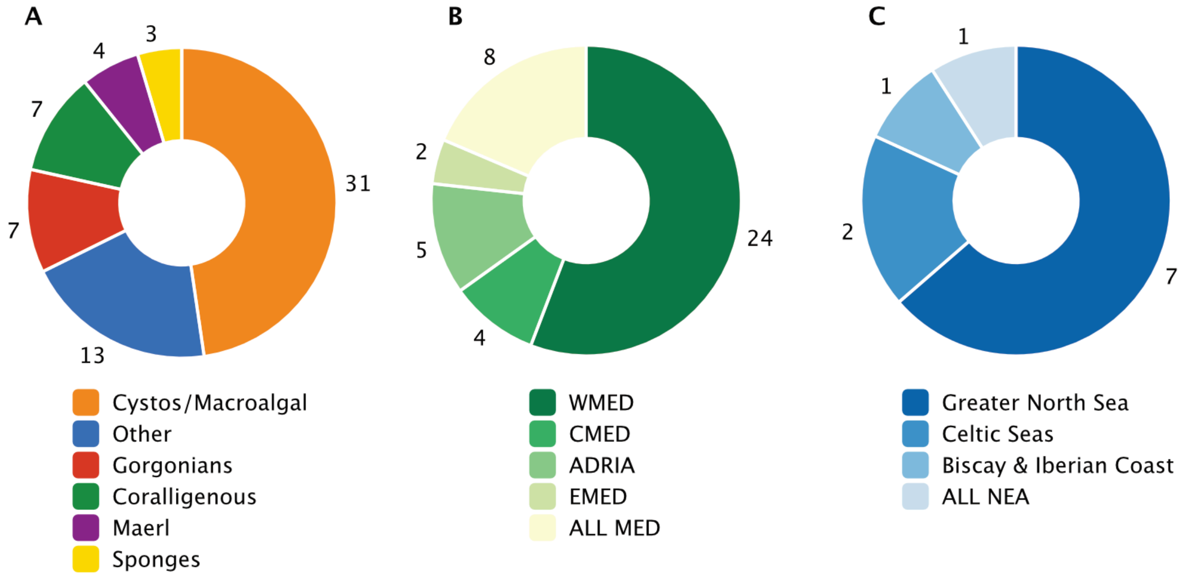


Figure 3.18. Degraded Sublittoral hard substrate habitat map entries by (A) different habitat types, (B) different sub-regions of the Mediterranean, and by (C) different sub-regions of the North-East Atlantic. (WMED: Western Mediterranean; CMED: Ionian Sea and the Central Mediterranean; Adriatic: Adriatic Sea; EMED: Aegean-Levantine Sea; ALL MED: All Mediterranean regions; ALL NEA: All North-East Atlantic Ocean regions; Greater North Sea: Greater North Sea, including the Kattegat and the English Channel).

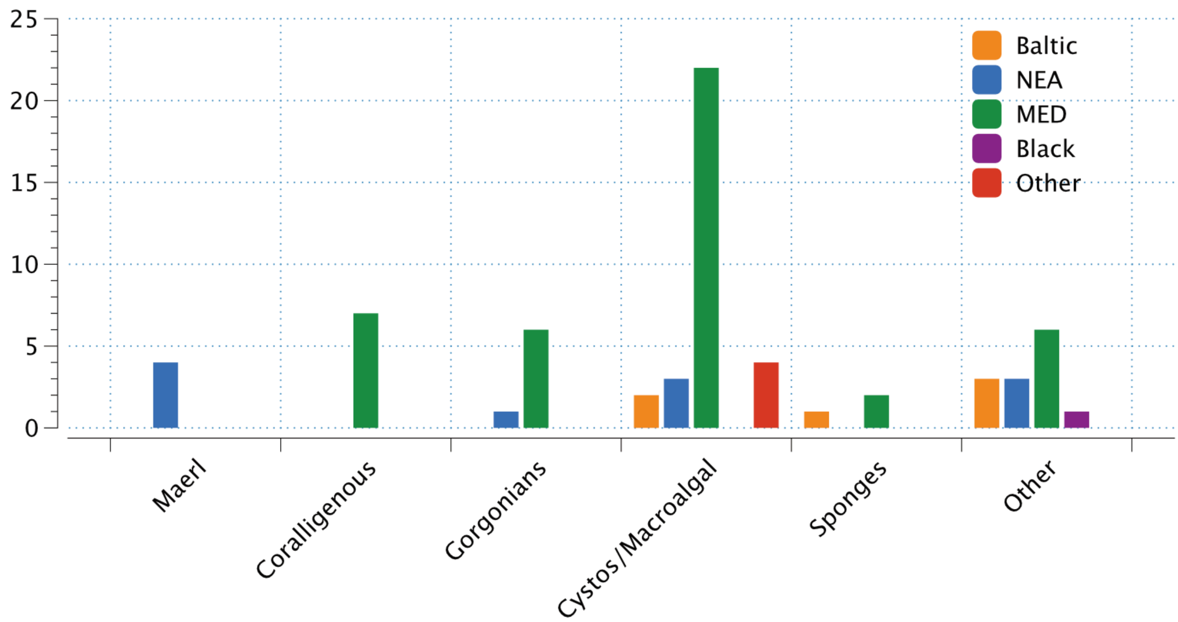


Figure 3.19. Degraded sublittoral hard substrate map entries by habitat types and region. (Cystos/Macroalgal: *Cystoseira*/Macroalgal forests/beds; Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)).

3.2.1.4 Degraded Habitat Maps in Areas of Importance

Almost 60% of the entries within the catalogue are considered Sensitive Habitats (SH)/Vulnerable Marine Ecosystems (VMEs). Within the Mediterranean Sea and the North-East Atlantic Ocean, all forms of

Sensitive habitats/VMEs are identified with maerl beds, coral gardens, sponge beds and seagrass meadows predominating. Within the Baltic Sea, there are 8 entries including *Zostera* meadows, sponge beds, reefs and aphotic rock and boulders or mixed hard and soft substrates dominated by sea anemones (Figure 3.20) Within the Norwegian coast, *Zostera* meadows and kelp forests of *Saccharina latissima* (Figure 3.20) and in the Black Sea the only degraded habitats that are considered areas of importance are reef habitats reported under the Article 17 formal assessments of the Habitats Directive under the Habitat code H1170 Reefs. On a global scale, seagrass meadows and hydrothermal vents are included.

There are 72 entries (36%) relating to areas of conservation importance, the majority of which occur in the Mediterranean Sea (Figure 3.20) which contains *Posidonia* meadows, *Cystoseira* forests, coralligenous assemblages, gorgonian forests, and deep-sea canyons and coral gardens. Within the Northeast Atlantic entries included *Zostera* meadows, deep-sea canyons, corals and seamounts, whilst reefs were found in the Black and the Baltic seas and *Zostera* meadows and kelp forests on the Norwegian coast.

There are 115 entries (57%) considered Priority and Protected Species/Habitats, with the majority found in the Mediterranean and the North-East Atlantic (Figure 3.20). In the Mediterranean Sea, there are several vegetated (*Posidonia* beds and macroalgal forests), deep-sea (coral gardens and canyons) and sublittoral hard substrate (coralligenous assemblages and gorgonian forests) habitats. Whilst there are several types of sublittoral hard substrate (i.e. maerl beds, gorgonian forests) and deep-sea habitats (i.e. seamounts, hydrothermal vents, sponge beds and coral gardens) in the North-East Atlantic. Outside of these regions degraded *Zostera* meadows, aphotic rock and boulders or mixed hard and soft substrates dominated by sponges and sea anemones respectively were found in the Baltic and seagrass meadows and kelp forests are among the degraded habitats on the Norwegian coast.

A low percentage of the entries included or originated from Marine Protected Areas (MPAs) (37: 14%), with the majority of entries coming from the Mediterranean Sea (33: 89%), with no MPAs reported in the Baltic Sea and in areas non-EU countries, such as Norway ("reported" meaning that we have no entries saying they belong to an MPA, Figure 3.20). Mapped MPAs in the NEA include coral gardens and *Zostera* meadows, while in the Mediterranean several vegetated (e.g. *Posidonia* meadows, *Zostera* meadows, *Cystoseira* beds), coralligenous assemblages, gorgonian forests and sponge beds, and deep-sea habitats (coral gardens and canyons) were included.

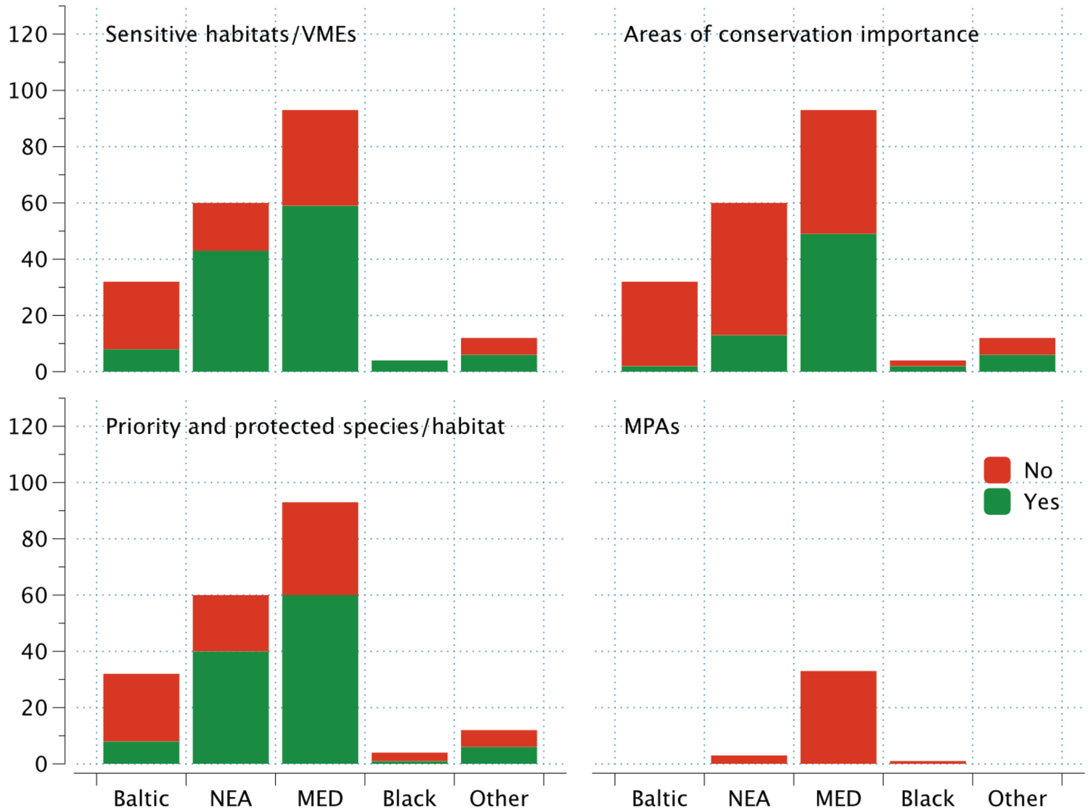


Figure 3.20. Degraded habitat map resource entries by region with respect to Sensitive Habitats (SH) /Vulnerable Marine Ecosystems - VMEs, Areas of Conservation Importance, Priority and Protected Species/Habitats, and Marine Protected Areas (MPAs). (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)).

3.2.2 Assessment status of degraded marine habitats

The state of habitat degradation has been assessed in 28% (56) of the map entries (Figure 3.21). The majority of these derive from large-scale habitat assessments undertaken by international organizations and commissions (e.g. IUCN European Red List of Habitats, HELCOM Red List Biotope Information Sheets, European Environmental Agency, Reports under the Article 17 of the Habitats Directive, and OSPAR Commission). The majority of these assessments have taken place in the North-East Atlantic Ocean, followed by the Mediterranean and the Baltic seas (Figure 3.22). The vast majority of these habitats (51: 91%) have been found to be in an Unfavourable/SubGES environmental status (GES being Good Environmental Status as defined by the MSFD).

In most entries (96: 48%), the status of degradation has been observed, often indirectly, by individual studies (e.g. presence of negative impacts from various activities and pressures, decline in cover, loss of habitat-forming key species) (Figure 3.21). These studies mostly concern sublittoral soft and hard substrate habitats of the Mediterranean Sea (Figures 3.22 and 3.23). Modelled or predicted status of degradation account for 11% (23) of the entries (Figure 3.21) and are derived from publications that use cumulative impact scores and indices at a basin or global scale. For 7% (14) of the entries, habitats are assumed to be degraded based on the presence of lost fishing gear and historical intensive trawling. These entries are predominately in deep-sea habitats in the Mediterranean Sea (Figures 3.22 and 3.23).

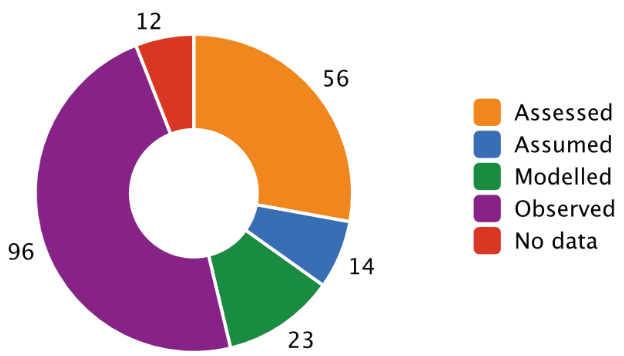


Figure 3.21. Number of degraded habitat map entries per category of assessment status.

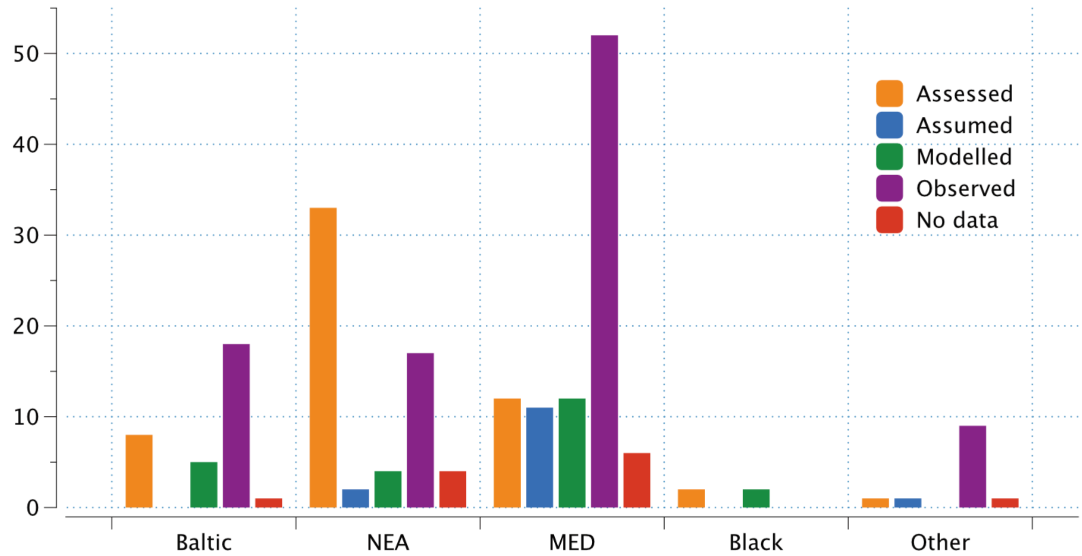


Figure 3.22. Number of degraded habitat map entries by region with respect to their assessment status. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)).

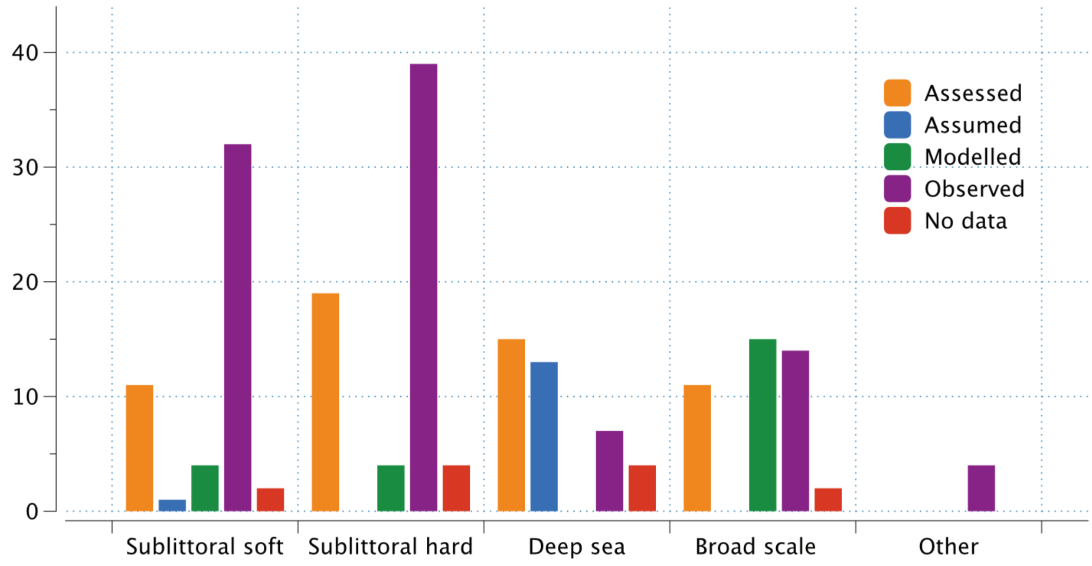


Figure 3.23. Number of degraded habitat map entries by major habitat type with respect to their assessment status.

3.2.2.1 Type of information on the extent of decline of degraded marine habitats

Information relating to the extent of decline in degraded marine habitats is descriptive/qualitative in nature or absent in most entries (75: 37% each) (Figure 3.24) with numerical/quantitative only present in 25% (51) of the entries. Where this information is available it is predominately expressed as a percentage of habitat loss, in terms of cover (e.g. "*the quantity of the biotope is estimated to have declined >25% in the past 50 years*"). However, in a few cases different case-specific metrics are used, such as decrease in seagrass biomass, seagrass shoot density or density of gorgonian forests at a given site. Numerical/quantitative information is mainly provided for sublittoral soft and hard substrate habitats of the Mediterranean Sea while the extent of decline for deep-sea habitats is mainly given in a descriptive/qualitative manner (Figures 3.25 and 3.26).

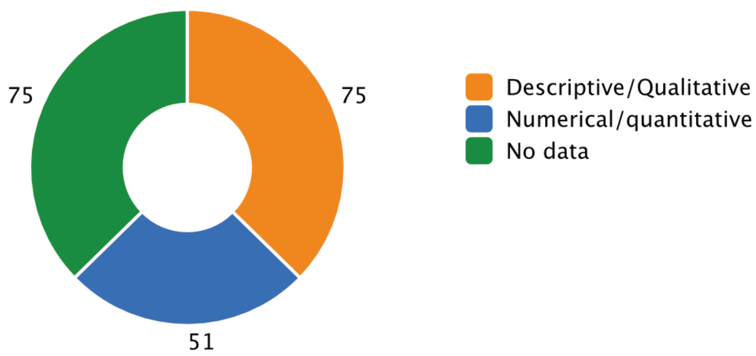


Figure 3.24. Number of degraded habitat map entries with respect to the type of information on the extent of habitat decline.

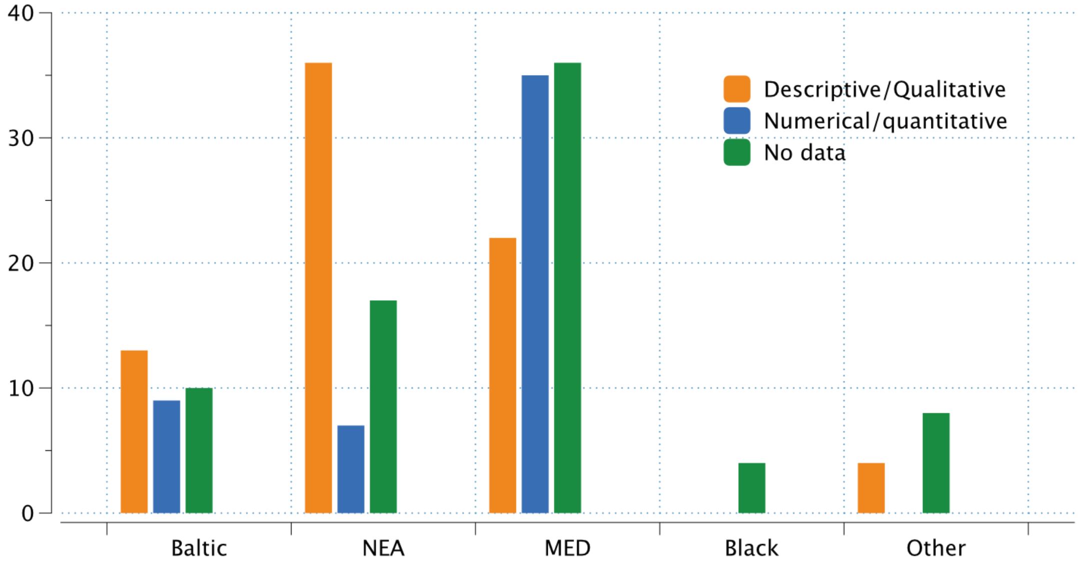


Figure 3.25. Number of degraded habitat map entries by region with respect to the type of information on the extent of habitat decline. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)).

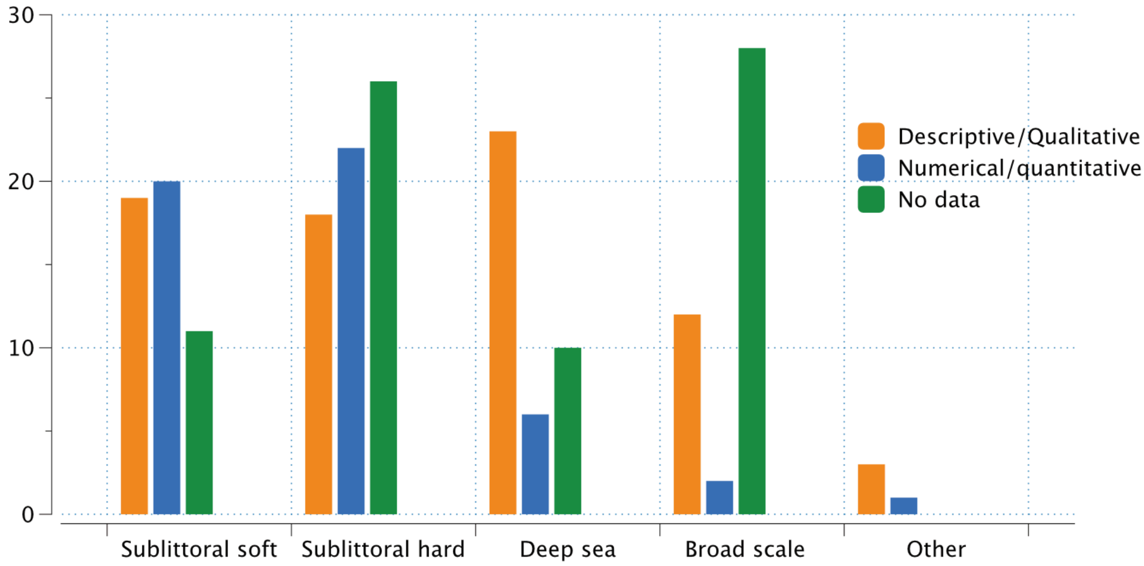


Figure 3.26. Number of degraded habitat map entries by major habitat type with respect to the type of information on the extent of habitat decline.

3.2.2.2 Information on the recovery/restoration potential of degraded marine habitats

The majority of entries reporting degraded habitats (121: 60%) do not include information on their recovery/restoration potential (Figure 3.27). Of those that do, 80 entries (40%) indicate the potential for restoration/recovery classified as: Yes – Opinion (45: 22%) and Yes – Assessed (7: 3.5%), while 28 entries (14%) indicate a low/poor potential for recovery/restoration. The former category included entries that provided some form of opinion-based suggestions to achieve habitat recovery/restoration, while the few assessed entries provided specific or quantitative suggestions based on experimental data (e.g. recolonization and transplantation tests for seagrass species and sea urchin removal). Interestingly, low/poor potential for recovery/restoration was mostly reported in the North-East Atlantic Ocean (Figure 3.28), specifically for deep-sea habitats like coral gardens and sponge aggregations (Figure 3.29). Although little information was available on the recovery potential of these habitats, however, there is a general consensus that highly impacted coral colonies are unlikely to recover due to their slow growth rate, coupled with the increasing degree of human-induced impacts.

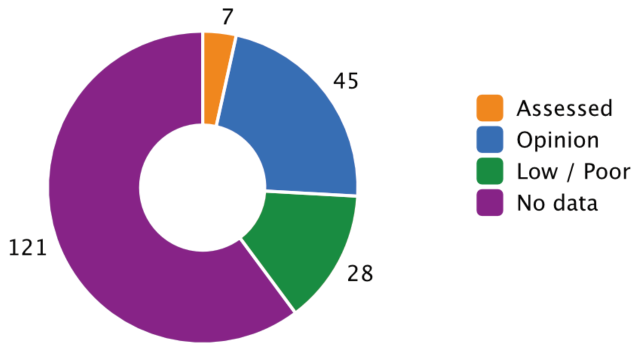


Figure 3.27. Number of map entries with respect to the recovery/restoration potential of the degraded habitats.

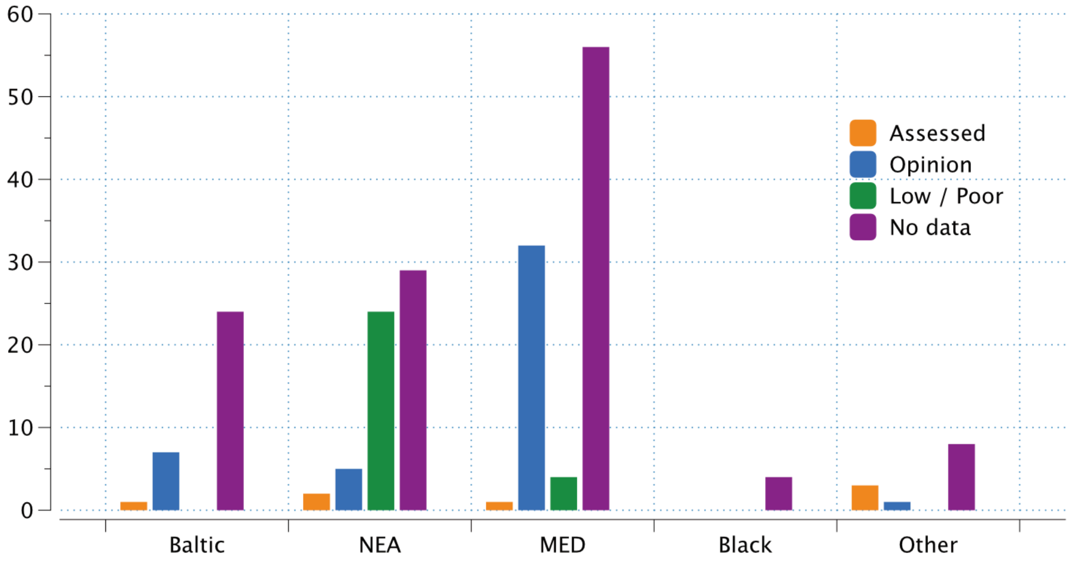


Figure 3.28. Number of map entries by region with respect to the recovery/restoration potential of the degraded habitats. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)).

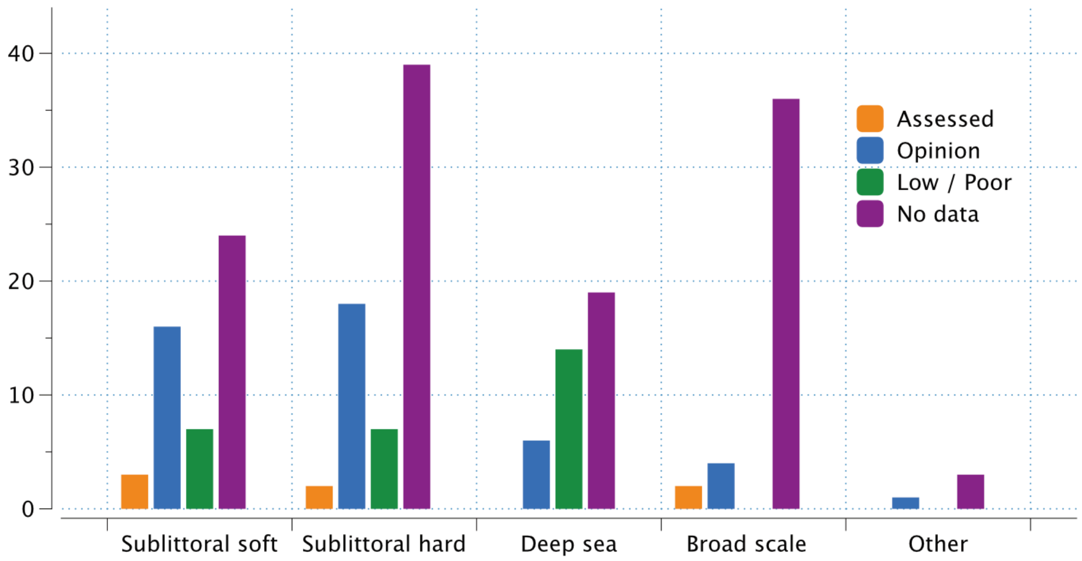


Figure 3.29. Number of map entries by major habitat type with respect to the recovery/restoration potential of the degraded habitats.

3.2.2.3 Suggested restoration actions for degraded marine habitats

Most of the entries (145: 72%) do not suggest specific restoration actions for the reported degraded habitats (Figure 3.30), rather, the most frequently suggested type of restoration is mitigation or removal of the activities which caused the degradation (40: 20%), such as the adoption of restrictions to fishing activities (e.g. bottom trawling) or the establishment of MPAs. Active restoration is suggested as a measure only in 11 catalogue entries (6%), specifically: seagrass transplantation (5 entries), sea urchin removal in *Cystoseira*/macroalgal forests (5 entries) and the establishment of filter feeding bivalves to decrease turbidity (1 entry). Moreover, 5 entries suggest a combination of mitigation/removal of activities and active restoration.

Active restoration was mostly suggested in the Mediterranean and the Baltic Sea (Figure 3.31), specifically for soft and hard substrate habitats (Figure 3.32), while mitigation was suggested in the Mediterranean and the Black Sea (Figure 3.31) and for all the reported types of degraded habitats (Figure 3.32).

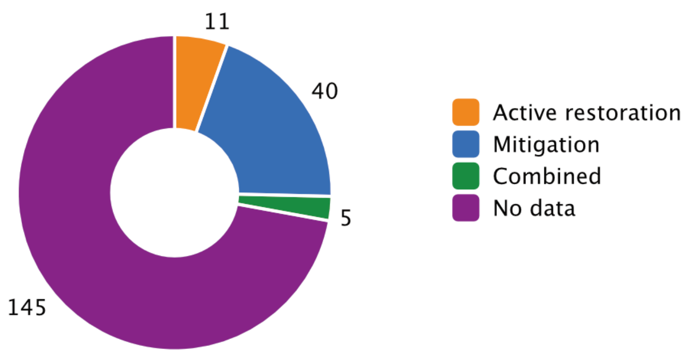


Figure 3.30. Number of map entries with respect to the suggested restoration action for degraded marine habitats. Combined means a combination of active restoration and mitigation.

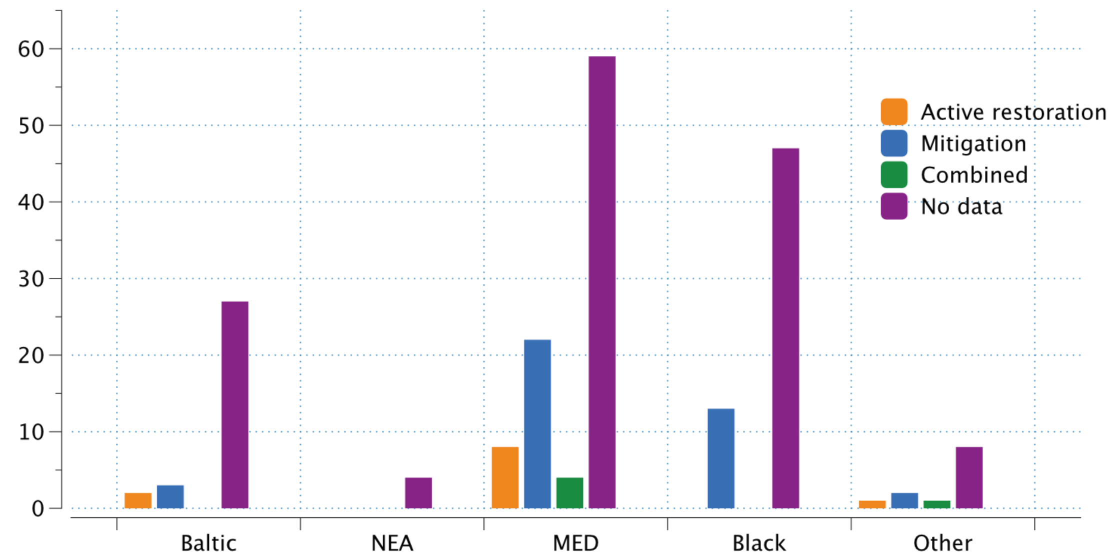


Figure 3.31. Number of map entries by region with respect to the suggested restoration action for degraded marine habitats. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)). Combined means a combination of active restoration and mitigation.

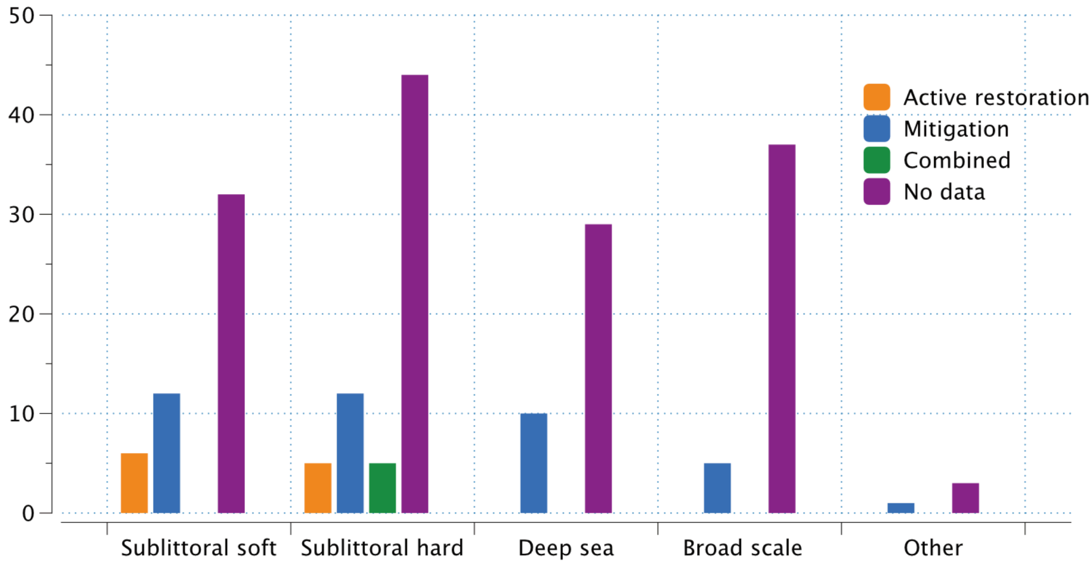


Figure 3.32. Number of map entries by major habitat type with respect to the restoration action for degraded marine habitats as suggested in the Degraded habitat catalogue. Combined means a combination of active restoration and mitigation.

3.2.2.4 Activities reported on degraded marine habitats

Most entries (126: 63%) reported multiple activities taking place in the vicinity of the degraded habitats, while only 24% (47 entries) reported a single activity (Figure 3.33) whilst information on activities was not available for 28 entries (14%). "Multiple activities" were listed as the main type of pressure found in all marine regions (Figure 3.34) except for regions that fall outside EU waters, and in all major habitat types, except for those of the deep sea, where marginally more single activities were reported (Figure 3.35).

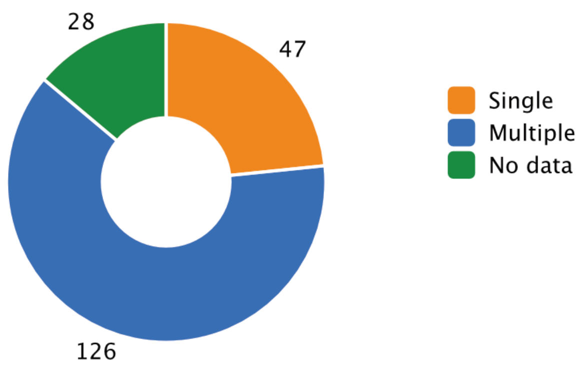


Figure 3.33. Number of degraded habitat map entries with respect to the reported activities. Single: single activity; Multiple: multiple activities.

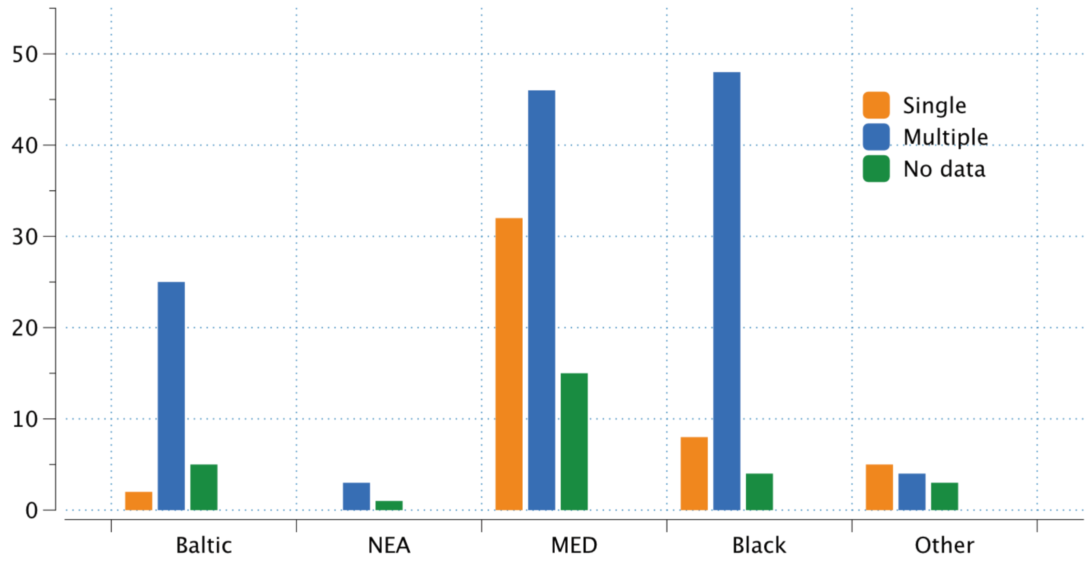


Figure 3.34. Number of degraded habitat map entries by region with respect to the reported activities. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)). Single: single activity; Multiple: multiple activities.

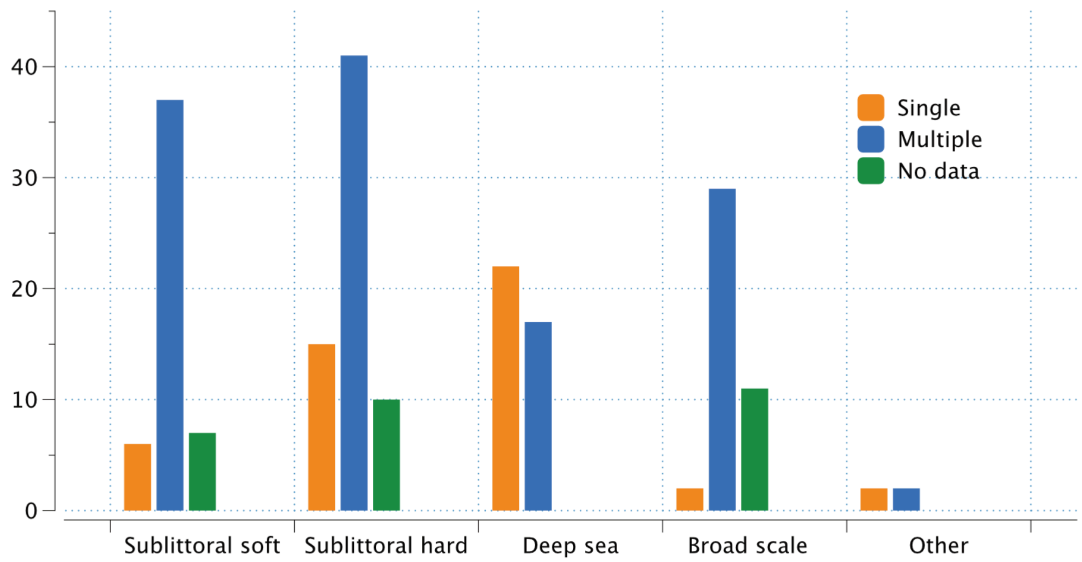


Figure 3.35. Number of degraded habitat map entries by major habitat type with respect to the reported activities. Single: single activity; Multiple: multiple activities.

Extraction of living resources was by far the most frequently reported activity causing habitat degradation (104 entries), followed by unspecified activities leading to eutrophication (47 entries), coastal and marine structure infrastructure (44 entries) and extraction of non-living resources (33 entries) (Figure 3.36). Extraction of living resources was also by far most frequently reported as a single activity causing habitat degradation (36 entries) (Figure. 3.37).

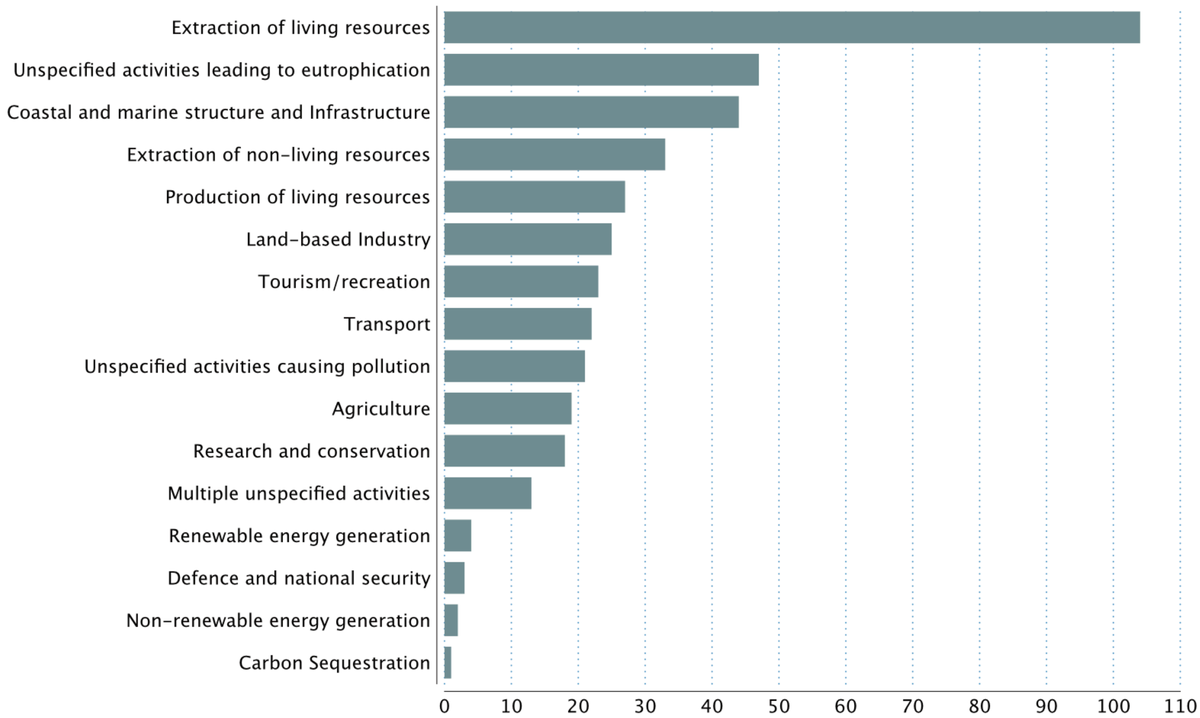


Figure 3.36. Activities reported in the degraded habitat map entries in decreasing order of frequency.

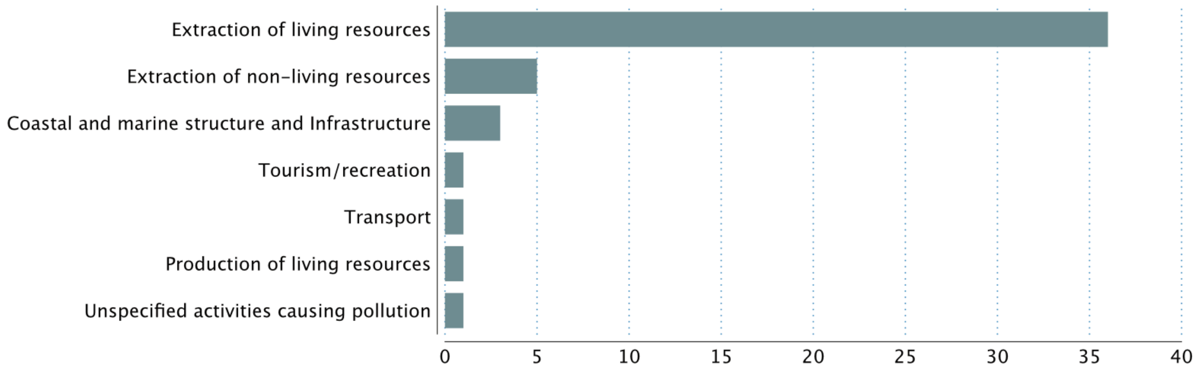


Figure 3.37. Activities reported as single activities entries (i.e. the only activity reported) in the degraded habitat map entries in decreasing order of frequency.

Of the single pressures considered, extraction of living resources was the most frequently reported activity in all regions investigated, except for the Baltic Sea where unspecified activities leading to eutrophication was the most common activity (Figure 3.38). Extraction of non-living resources and research and conservation were more frequently reported in the North-East Atlantic Ocean while production of living resources and unspecified activities causing pollution were more frequently reported in the Mediterranean Sea.

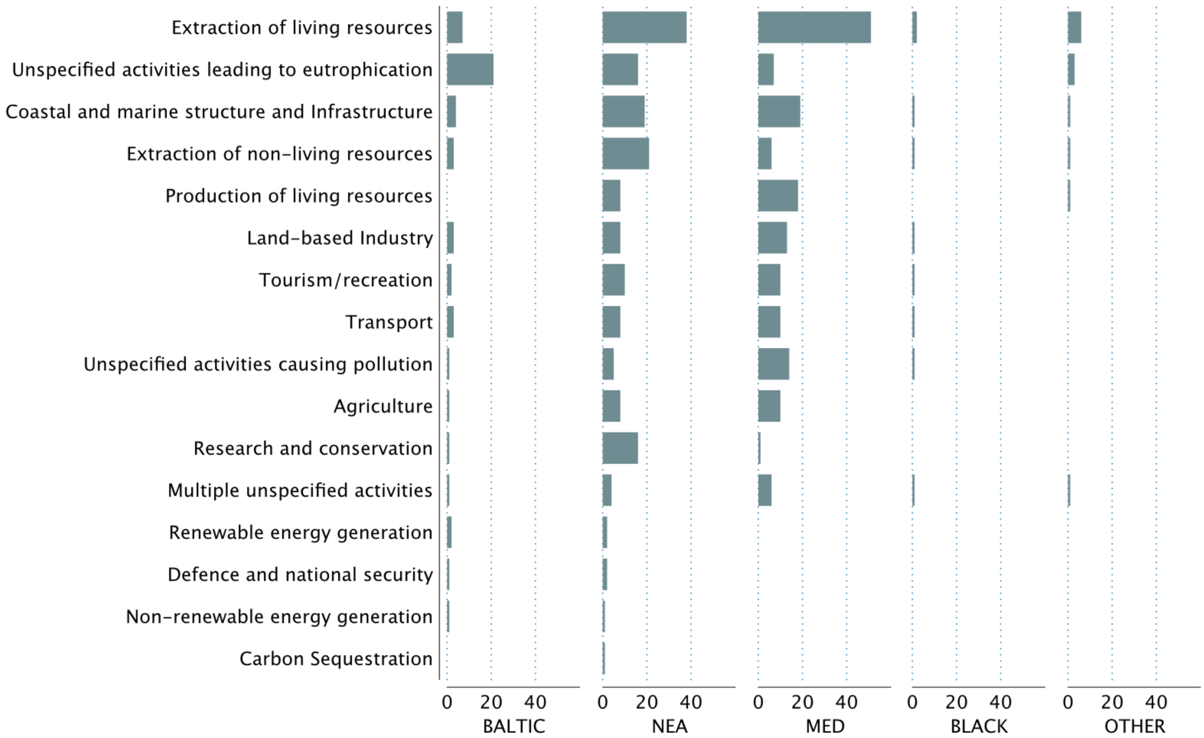


Figure 3.38. Activities entries by region in the degraded habitat map entries in decreasing order of frequency.

Extraction of living resources was the most frequently reported activity in all major habitat types, except in or broad scale map (mostly from the Baltic Sea) where unspecified activities leading to eutrophication dominated (Figure 3.39). Pressures arising from the production of living resources was mainly reported in sublittoral soft and hard substrate habitats; tourism and recreation in sublittoral hard substrate habitats (e.g. SCUBA diving); extraction of non-living resources (e.g. oil, gas and minerals exploration) and research and conservation (e.g. scientific sampling and trawling surveys) in deep-sea habitats (mostly in the North-East Atlantic Ocean). Interestingly, agriculture was reported to affect deep-sea habitats, as "emissions and input from agriculture", along with land-based industry (OSPAR 2008).

In deep sea habitats, the impacts of coastal and marine structure and infrastructure were mostly related to "dumping activities" and submarine communication cables. Anchoring was also reported as an activity in 16 catalogue entries (11 entries on seagrass meadows), though they did not explain whether it was anchoring by fishing boats (extraction of living resources), leisure (tourism/recreation) or any other type of boats (transport). Trampling was also reported as an ongoing activity in 2 seagrass meadows and 2 *Cystoseira*/macroalgal forests) entries, though it was not defined whether it was caused by tourism/recreation or other human activities, therefore, these two activities were not incorporated in the analysis.

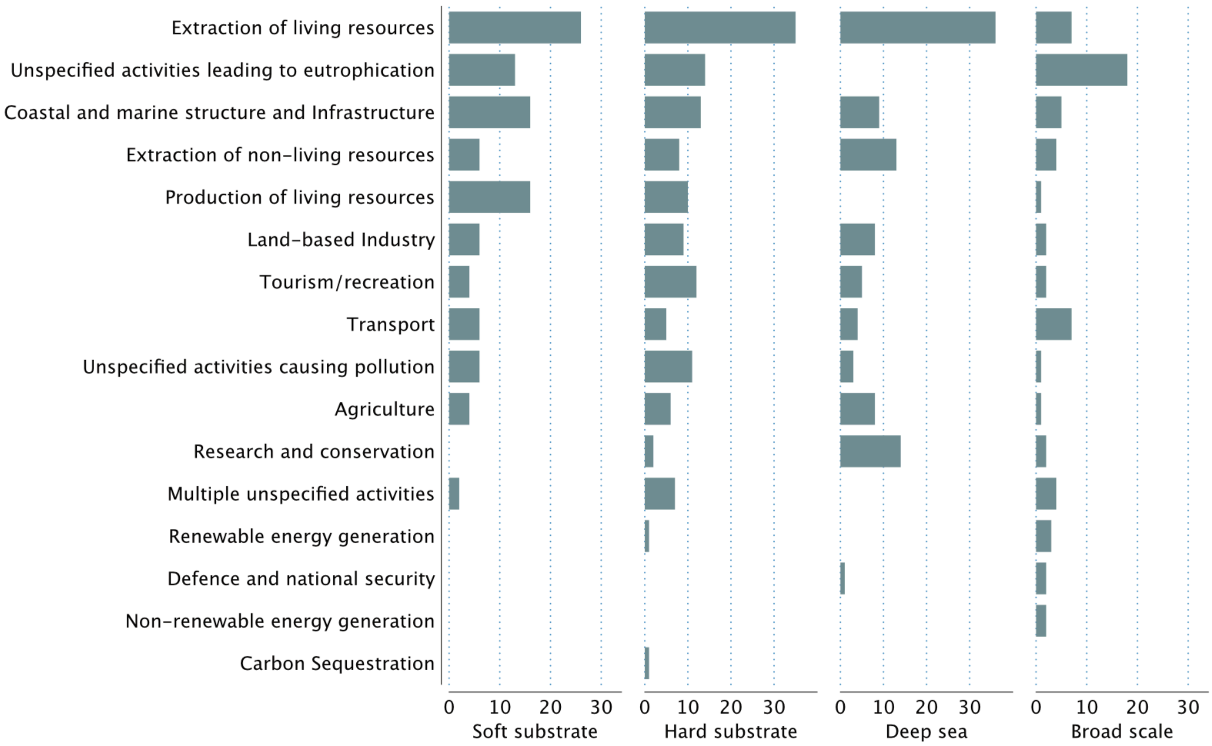


Figure 3.39. Activities entries by major habitat type in the degraded habitat map entries in decreasing order

3.2.2.5 Pressures reported on degraded marine habitats

Most entries (120: 60%) reported multiple types of pressures on the degraded habitats while a single type of pressure was reported in only 52 entries (26%) (Figure 3.40), whilst information on pressures was not available for 29 entries (14%). Multiple pressures were noted in all marine regions and mostly in the Mediterranean and in the Black Seas (Figure 3.41), and in all major habitat types (Figure 3.42).

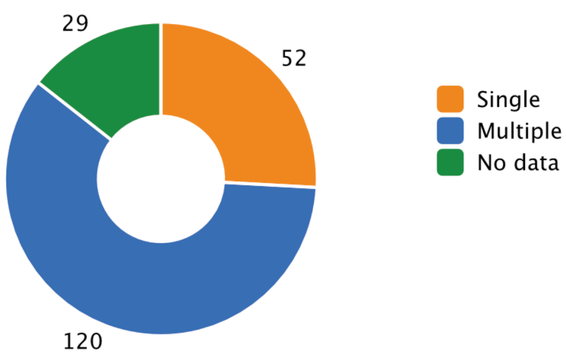


Figure 3.40. Number of degraded habitat map entries with respect to the reported pressures. Single: single pressure; Multiple: multiple pressures.

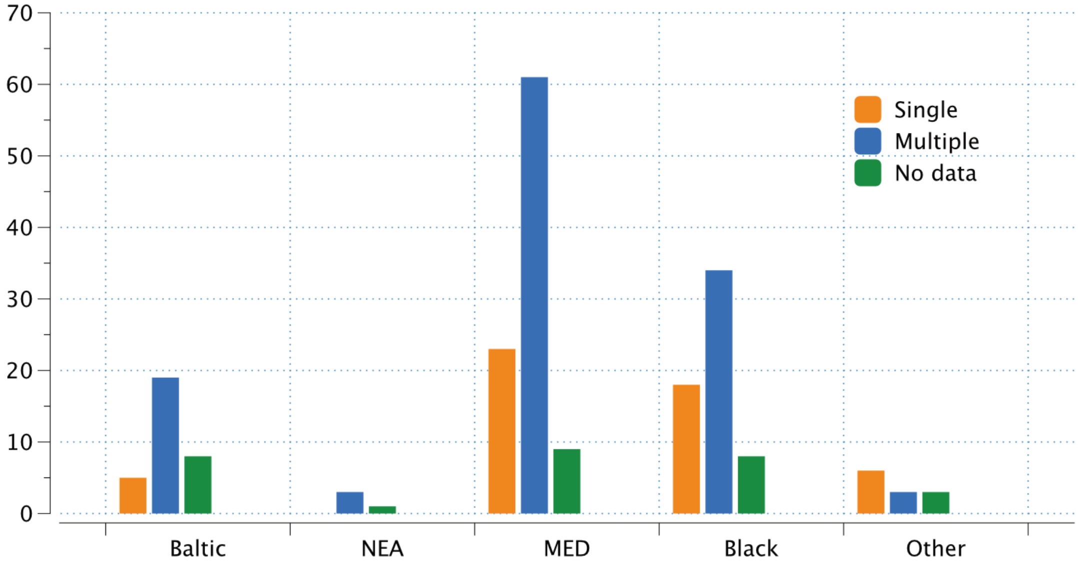


Figure 3.41. Number of degraded habitat map entries by region with respect to the reported pressures. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)). Single: single pressure; Multiple: multiple pressures.

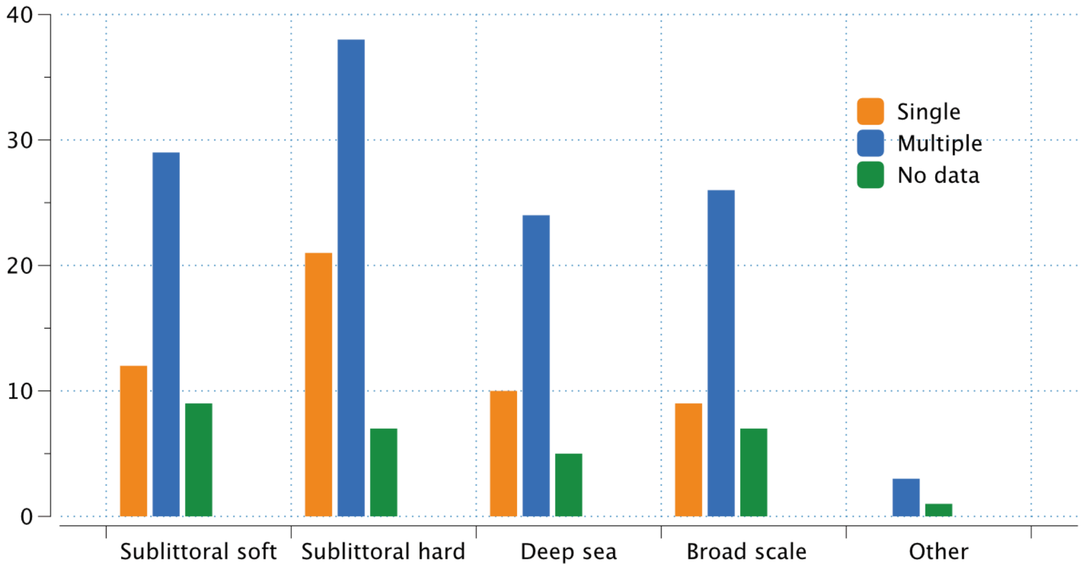


Figure 3.42. Number of degraded habitat map entries by major habitat type with respect to the reported pressures. Single: single pressure; Multiple: multiple pressures.

Changes in siltation and light (often reported as sedimentation) and abrasion are both described as consequences of bottom trawling and are the most frequently reported endogenous pressures (i.e. manageable within a local system) on degraded habitats (57 and 54 entries, respectively), followed by nutrient enrichment (38 entries) (Figure 3.43). Abrasion (22 entries), changes in siltation and light (12 entries), followed by litter (10 entries) also the most frequently reported single endogenous pressures (Figure 3.44).

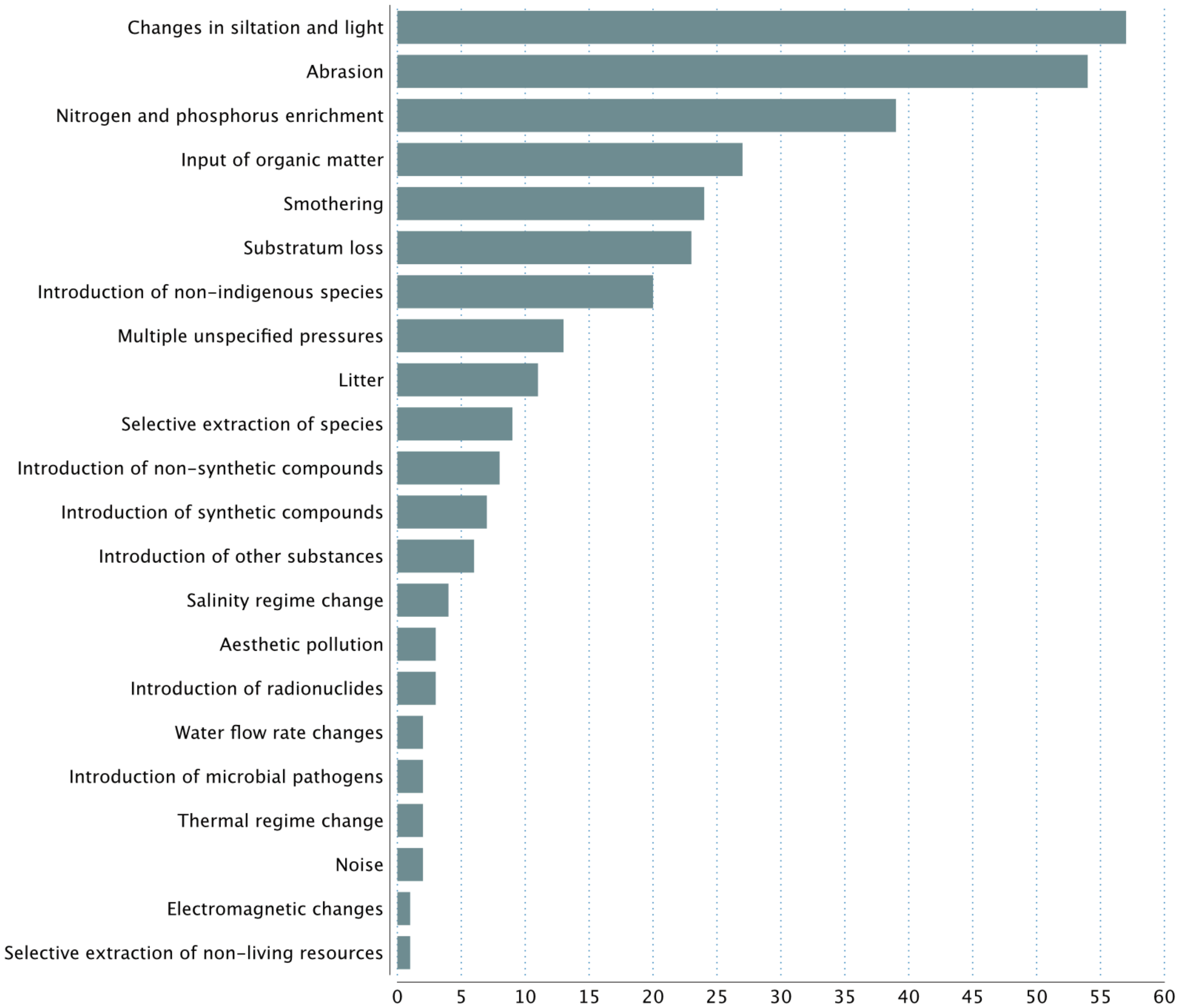


Figure 3.43. Endogenous pressures (i.e. manageable within a local system) reported in the degraded habitat map entries in decreasing order of frequency.

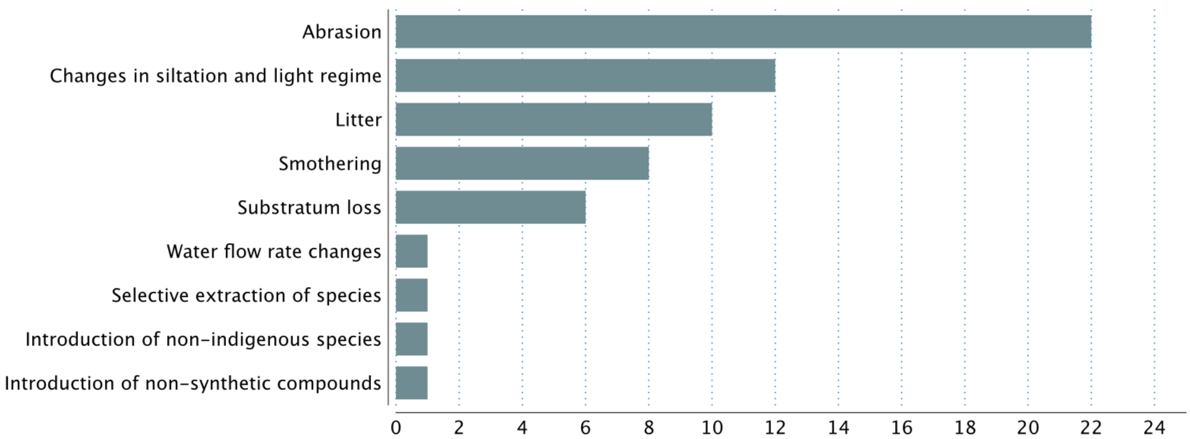


Figure 3.44. Endogenous pressures (i.e. manageable within a local system) reported as single pressures entries (i.e. the only pressure reported) in the degraded habitat map entries in decreasing order of frequency.

The most frequently reported endogenous pressure differed between regions, with nutrient enrichment along with organic matter input being the most prevalent in the Baltic Sea, changes in siltation and light in the North-East Atlantic and abrasion in the Mediterranean Sea (Figure 3.45).

Figure 3.45. Endogenous pressures (i.e. manageable within a local system) entries by region in the degraded habitat map entries in decreasing order of frequency. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)).

The most frequently reported endogenous pressure also differed between habitats with changes in siltation and light along with abrasion mainly reported on sublittoral soft and hard substrate and nutrient enrichment along with organic matter input mostly reported across broad scale entries (Figure 3.46).

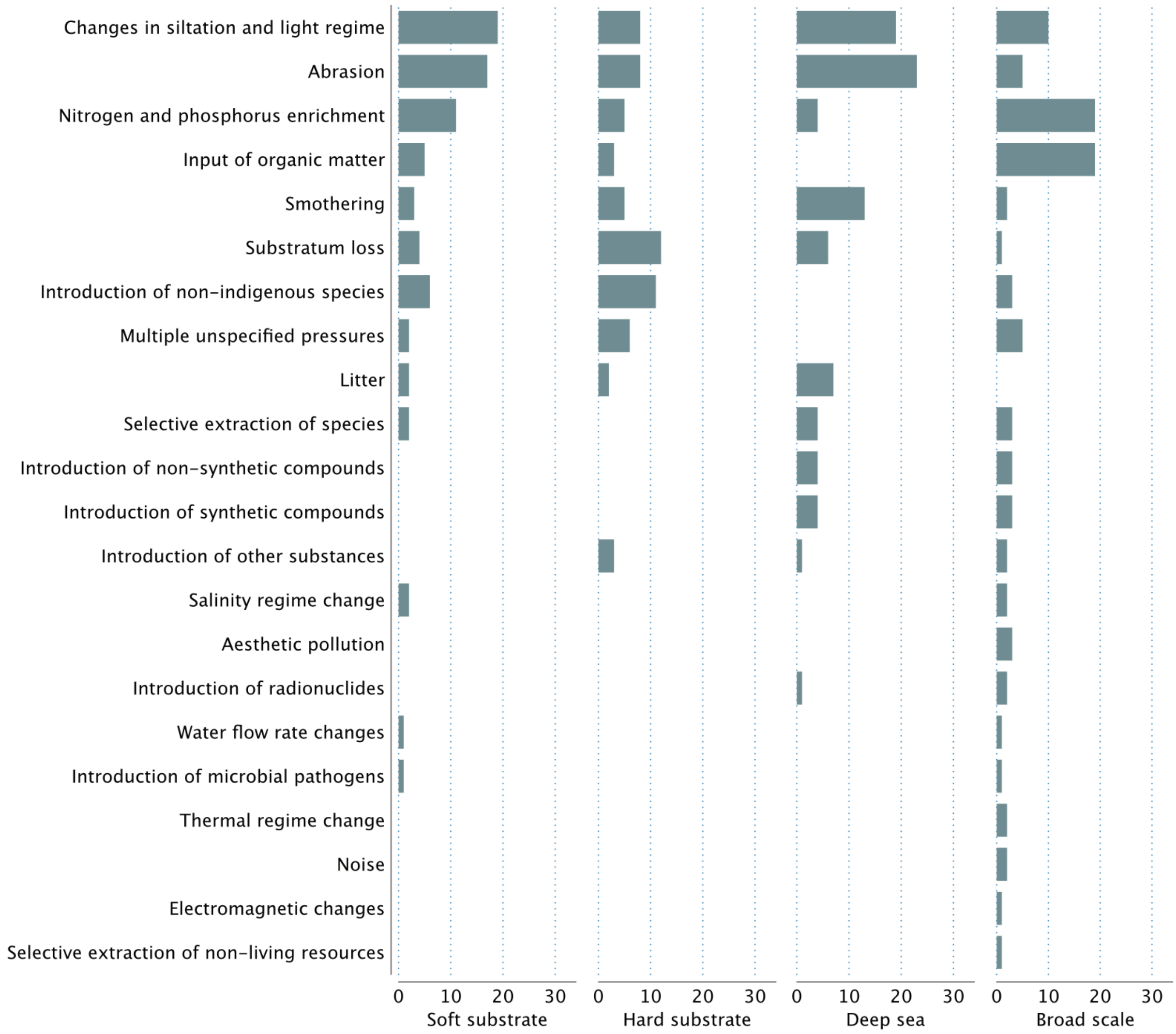


Figure 3.46. Endogenous (i.e. manageable within a local system) pressures by major habitat type in the degraded habitat map entries in decreasing order of frequency.

Thermal regime change and climate change (as a general unspecified type of exogenous pressure) were the most frequently reported types of exogenous pressures on degraded habitats (28 and 22 entries, respectively), followed by pH changes (8 entries) (Figure 3.47). Thermal regime change and climate change were the only types of exogenous pressure that were reported as single pressures (3 and 3 entries, respectively).

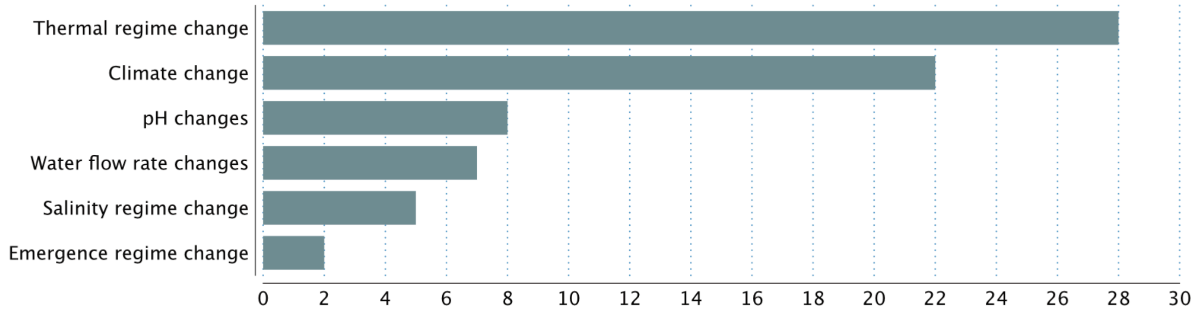


Figure 3.47. Exogenous pressures (i.e. unmanageable with local measures) reported in the degraded habitat map entries in decreasing order of frequency.

The most frequently reported exogenous pressure also differed by region with thermal regime change and climate change most reported in the North-East Atlantic and the Mediterranean Sea and general climate change the only exogenous pressure reported in the Baltic Sea (Figure 3.48). The same types of exogenous pressures were also the most reported for all major habitat types (Figure 3.49).

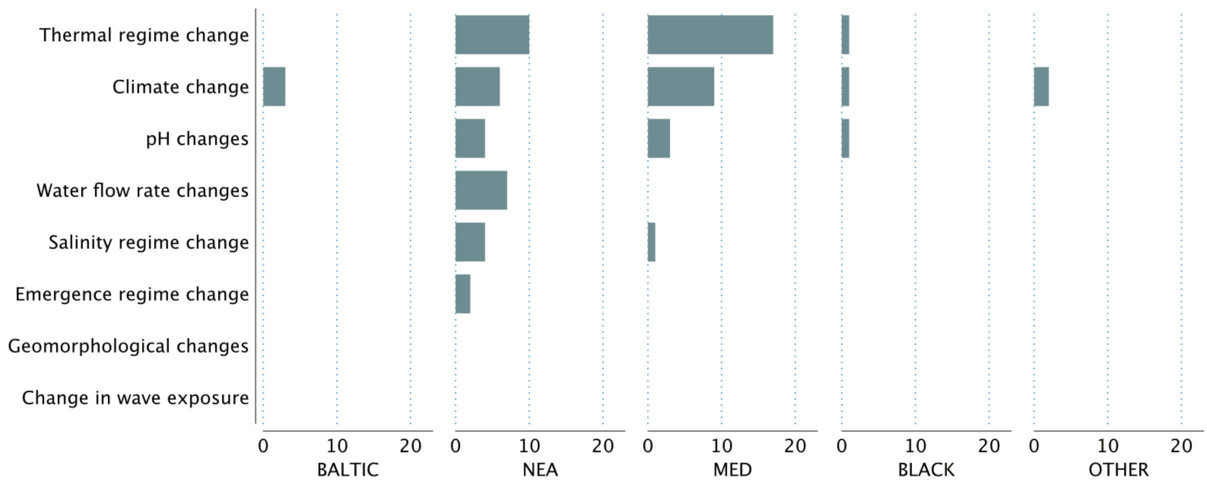


Figure 3.48. Exogenous pressures (i.e. unmanageable with local measures) entries by region in the degraded habitat map entries in decreasing order of frequency. (Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea; Black: Black Sea; Other (Non-European Regional Seas or Global maps)).

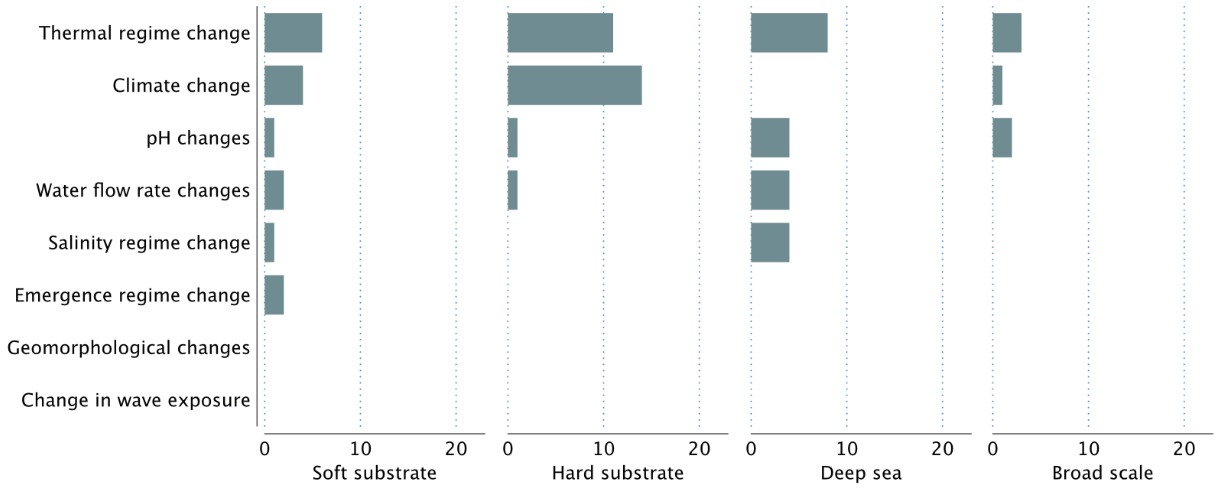


Figure 3.49. Exogenous pressures (i.e. unmanageable with local measures) by major habitat type in the degraded habitat map entries in decreasing order of frequency.

Sixteen entries reported pressures which could not be assigned to any of the categories followed within MERCES (see Methods and Materials). Such cases were: sea urchin overgrazing phenomena on *Cystoseira*/macroalgal forests (10 entries in the Mediterranean Sea), which however could be regarded as an indirect effect of overfishing; mucilaginous aggregates (1 record on Mediterranean *Cystoseira*/macroalgal forests); wasting disease on *Zostera* meadows (2 entries from the Baltic Sea and 3 from the North-East Atlantic Ocean); and exceptional storm events (3 entries on Mediterranean *Cystoseira*/macroalgal forests). Natural system modifications, biotic and abiotic processes were not taken into account in the systematic review (reported in few Mediterranean entries).

3.3. Features/properties of key habitats concerning restoration

3.3.1 Key Habitat Descriptions

Case study habitats were selected by the MERCES WP1 group in order to represent the MERCES focal habitat types (Shallow soft bottom habitats, Shallow hard bottom habitats and Deep-sea Habitats). The case study habitats were Mediterranean, Baltic and North Atlantic seagrass meadows, North-East Atlantic kelp forests (i.e. the two main forest building species in Norway, *Laminaria hyperborea* and *Saccharina latissima*), Mediterranean Sea macroalgal forests (shallow and deep *Cystoseira*), Mediterranean coralligenous assemblages, coral gardens in the Azores and deep-sea bottom communities in the Mediterranean basin and central-northern Atlantic (some of which are illustrated in Figure 3.50). The following chapters describe, for each of the cases, how specific characteristics among these features relate to important considerations when it comes to restoration. The general features, the specific characteristics and the consequences for restoration are summarized in Tables 3.2-3.9.

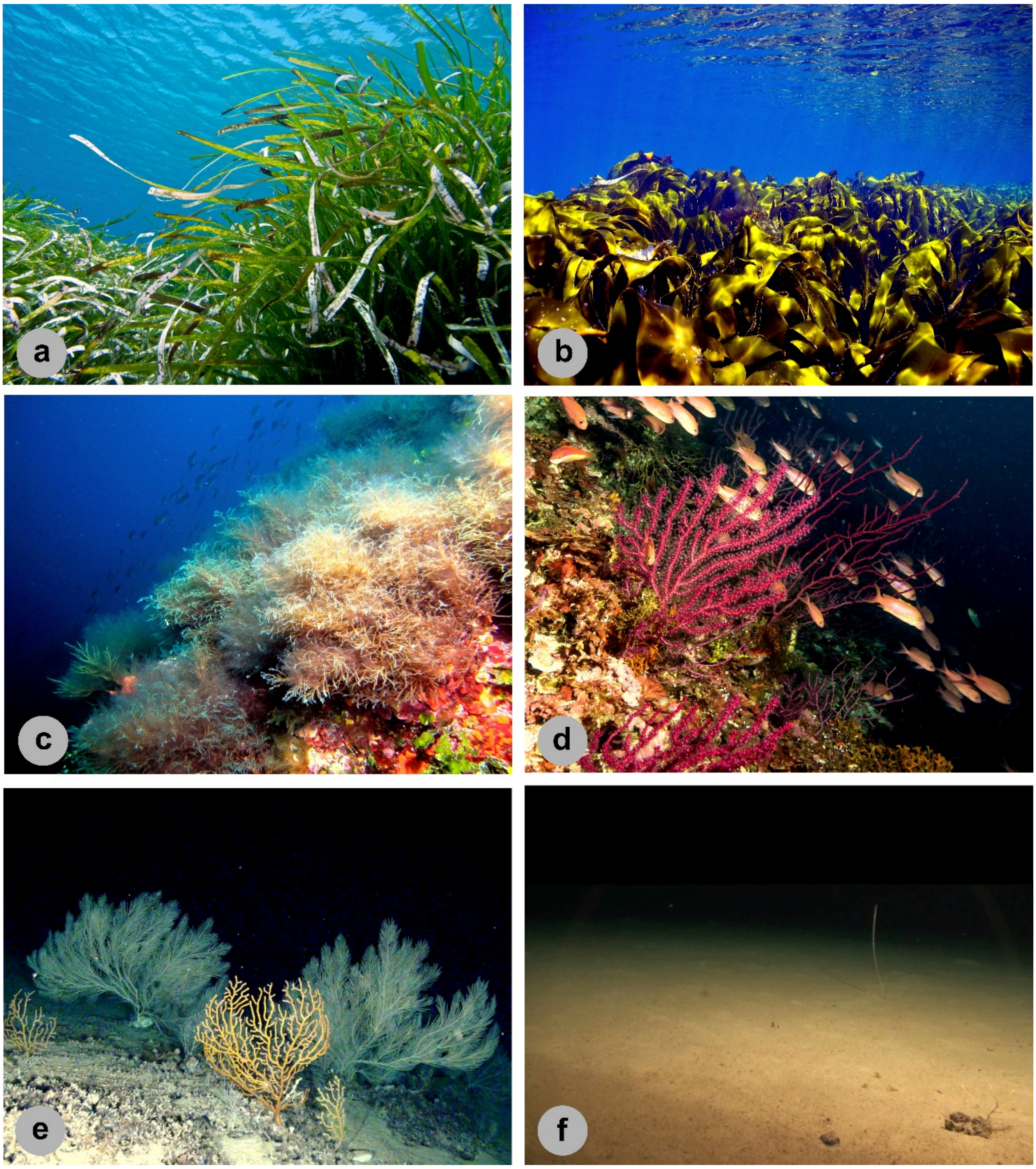


Figure 3.50. Case study habitats: (a) *Posidonia oceanica* meadow; (b) *Laminaria hyperborea* kelp forest; (c) *Cystoseira zosteroides* macroalgal forest; (d) Mediterranean coralligenous assemblage; (e) Deep-sea coral garden; (f) Deep-sea bottom community. Photos by Thanos Dailianis (a), Janne K. Gitmark (b), Cristina Linares (c, d), © OCEANA (e), Chris Smith (f).

3.3.1.1 Mediterranean, Baltic and North Atlantic - Shallow soft – Seagrass meadows

Seagrass meadows are widely recognized as key ecosystems in shallow coastal waters, supporting high associated biodiversity and providing numerous ecological services (den Hartog 1970, Cullen-Unsworth & Unsworth 2013). Seagrass meadows depend on good environmental conditions, such as clear waters, stable sediments and suitable nutrients for successful growth. They play several important ecological roles (Barbier 2011, Cullen-Unsworth & Unsworth 2013, Campagne et al. 2015, Nordlund et al. 2016), including providing habitat and nursery areas for a diverse assemblage of fish and invertebrate species, supporting complex trophic networks, filtering freshwater discharges from land, stabilising sediments, and significantly reducing coastal erosion. Seagrass meadows also play a major role in the carbon cycle and can store large amounts of carbon (Mcleod et al. 2011, Trevathan-Tackett et al. 2015, Röhr et al. 2016, Dahl et al. 2016). Several seagrass species are considered as keystone habitat forming and ecosystem engineering species (Jahnke et al. 2016) and are legally protected under various policies (e.g. NATURA 2000 Habitats Directive).

Dynamics – Dynamics vary greatly depending on the seagrass species. *Posidonia oceanica* is slow growing (vertical growth of 5-25 mm yr-1) but can live up to 30 years (Marbà et al. 1996, Marbà & Duarte 1997), *C. nodosa* is faster growing (up to 70 mm d-1) but shorter-lived (Cancemi et al. 2002). Both of these species spread vegetatively through the production of new shoots from horizontal rhizome growth, and also reproduce sexually through seeds. *P. oceanica* begins flowering in September and fruit formation from fertilized flowers lasts until the end of May, then the green fruits disperse by floating before sinking to the bottom and germinating, while *C. nodosa* flowers in the spring, while germination occurs 8-10 months later (Buia & Mazzella 1991). *Zostera marina* and Z. *noltii*, especially in the north, are also fast-growing species. In cold climates, eelgrass survives under ice cover during the winter months, but shoot elongation rates can reach >10 mm d-1in summer when light availability is high, (Olesen & Sand-Jensen 1993). In general, *Z. noltii* grows in the intertidal zone and can form large meadows in intertidal flats (such as in the Wadden Sea, Polte et al. 2005), while *Z. marina* usually grows both intertidally and subtidally, down to approx. 10 m depth (Bekkby et al. 2008). The reproductive strategies of *Zostera* vary: both species can reproduce sexually through the production of seeds, and asexually through rhizome propagation. In subtidal areas, *Z. marina* is a perennial plant, and reproduces both sexually and asexually (except in the Baltic Sea where it is limited to asexual reproduction potentially due to the low salinity, a short season or carbon limitation; Hellblom & Björk 1999). However, in the intertidal zone, *Z. marina* grows from seed annually, while *Z. noltii* is perennial with limited sexual reproduction and spreads mostly through vegetative propagation (Zipperle et al. 2009). In the northern Baltic (Finland), *Z. marina* is the only marine seagrass species to tolerate the low salinity, but relies almost exclusively on clonal growth (Reusch & Boström 2011).

Connectivity – Within seagrass meadows, clonal asexual reproduction ensures local growth. However, connectivity between seagrass meadows is poorly studied, though there are several mechanisms through which it could occur (McMahon et al. 2014). Some species, such as *P. oceanica*, have buoyant fruit which can disperse long distances and provide continued genetic flow between populations. Entire uprooted seagrass plants and negatively buoyant seeds can also disperse along the sediment if current speeds are high enough. Finally, herbivorous animals could transport seagrass fragments and seeds between populations.

Spatial distribution – In European waters, four native seagrass species can be found (Borum et al. 2004). *Zostera marina* can be found throughout European seas, *Zostera noltii* in all seas except the northernmost ones; *Cymodocea nodosa* and *Posidonia oceanica* are found in the Mediterranean Sea. An additional non-native species introduced from the Red Sea, *Halophila stipulacea*, is also present in the Mediterranean Sea. The depth distribution of seagrasses ranges from intertidal to 40 m depth and they can be found in wide range of salinity ranging from the brackish waters (5‰) of the Baltic to 37‰ in Mediterranean waters.

Vulnerability/fragility – Over their wide distribution range, seagrass meadows are prone to many anthropogenic pressures such as habitat loss, eutrophication, dredging, anchoring, invasive species, fisheries activities, coastal development, pollution and climate change (Short & Wyllie-Echeverria 1996, Short & Neckles 1999, Milazzo et al. 2004, Orth et al. 2006, Williams 2007, Boudouresque et al. 2009, Waycott et al. 2009). Across the world, an estimated 30% of seagrass meadows have been lost (Waycott et al. 2009). In the Mediterranean Sea, *P. oceanica* meadows are especially threatened, having decreased by 34% in the past 50 years (Telesca et al. 2015), due to decreased water quality from eutrophication, elevated shoot mortality due to climate change (Marbà & Duarte 2010) and physical disturbances such as anchoring, dredging, and coastal development. While protection measures such as marine protected areas have been enacted, and some conditions have improved somewhat, the slow growth rate of this species makes recovery extremely slow (Boudouresque et al. 2009). *C. nodosa* losses have also been noted, due to the same environmental pressures. *C. nodosa* is also especially threatened by invasive green algae *Caulerpa* spp., which can replace entire meadows. *Caulerpa* spp. can outcompete *C. nodosa* for nutrients, thus growing quickly at high densities and leading to extensive seagrass loss, especially in areas with high nutrient input (Cecherelli & Cinelli 1997, Cecherelli & Campo 2002). Historical records also indicate that decreased water quality has led to decreased depth limit of *Z. marina* in northern Europe (Boström et al. 2014). *Z. marina* is also susceptible to eelgrass wasting disease caused by *Labyrinthula zosterae*, which led to the loss of over 90% of eelgrass populations across the northern Atlantic in the 1930s (Muehlstein 1988), though most populations recovered to some extent.

Structural complexity – Seagrass meadows provide both above-ground (leaves and shoots) and below-ground (rhizomes and roots) complexity and stability in soft-bottom ecosystems. This attracts high numbers of fish species as well as epifaunal and infaunal invertebrates, which use the seagrass meadows for shelter and breeding grounds, while larger animals such as seabirds, dugongs, manatees and sea turtles feed directly on the seagrass (Waycott et al. 2009). Eelgrass structure also has an important effect on sedimentation: the above-ground canopy reduces flow velocity and increases sedimentation within the meadow (Bos et al. 2007), while below-ground rhizomes stabilise the sediment (Christianen et al. 2013). This leads to a positive feedback mechanism as stabilised sediments improve water clarity and thus seagrass growth (van der Heide et al. 2011).

Diversity – The importance of genetic diversity within seagrass populations is a relatively new concept, but several studies have shown that high genetic diversity increases population growth, primary production, community stability, as well as resistance and resilience to disturbances (Williams 2001, Procaccini et al. 2007, Salo & Gustafsson 2016). The fragmentation of seagrass meadows could therefore lead to reduced genetic diversity and increase their susceptibility to anthropogenic pressures. When it comes to species diversity, seagrasses often grow in mixed meadows, either with other seagrasses, or other aquatic plants in estuaries. For example, in the Mediterranean, *C. nodosa* and *Z. noltii* often grow intermixed in shallow waters (e.g. Guidetti & Bussoti 2000) while mixed meadows of seagrass and *Ruppia maritima* or *Ruppia cirrhosa* are found in bays and estuaries (e.g. Ribera et al. 1997). In northern waters, *Z. noltii* and *Z. marina* can grow together in shallow and intertidal waters. In the brackish Baltic Sea, *Z. marina* grows intermixed with freshwater plants such as *Ruppia maritima*, *Potamogeton* spp., and *Zannichellia palustris* (Boström et al. 2014). As genetic diversity within *Z. marina* is limited in the Baltic, plant species diversity in mixed meadows may have an effect on seagrasses themselves, as well as on associated species (Gustafsson & Boström 2009, 2013). When it comes to associated biodiversity, seagrass meadows provide food and shelter to abundant fish and invertebrate species, resulting in various interspecific relationships. Many of these relationships form important feedback mechanisms. For example, seagrasses offer shelter for invertebrates such as bivalves and grazers. Bivalves can then fertilize the sediment and increase seagrass growth (e.g. Peterson & Heck 2001), while grazers such as isopods can control epiphytic algae and enhance seagrass growth (Baden et al. 2010).

Table 3.2. Key features for the MERCES case study habitat seagrass meadows (shallow soft) in the Mediterranean, the Baltic Sea and N Atlantic and implications for restoration and thereby the chances of recovery (recovery potential).

Key features	Specific characteristics	Implications for restoration
Dynamics (Box 1 in Figure 4.6)	Low to high growth rates depending on the species (e.g. *Zostera* grows quickly, but *Posidonia* is quite slow) High longevity	Need for long time scales, especially for the slow-growing species. In fast-growing meadows, restoration may be faster.
Connectivity (Box 1 in Figure 4.6)	Varies depending on the area and species. In general, populations with high connectivity (gene flow) have higher genetic diversity, which provides resistance. The Baltic Sea is an exception, which is characterized by old, mega clones (i.e. genetically highly isolated meadows).	Ensure connectivity of meadows by planting in vicinity of donor sites. Create genetically diverse patches when transplanting. Presently unknown whether a single genotype patch or multiple genotype transplantation patch is more successful in the long term.
Spatial distribution (Box 3 in Figure 4.6)	Mostly widespread, but depends on the species. *Zostera marina* and to some extent *Z. noltii* is spread across the northern hemisphere, *Posidonia oceanica* is limited to the Mediterranean, but is widespread there.	Restoration over large spatial scales is likely to increase probability of success. Widely distributed species implies more easy access to donor populations, and in particular nearby donor sites.
Vulnerability/fragility (Box 2 & 4 in Figure 4.6)	Seagrasses are very vulnerable to eutrophication (due to increased turbidity and overgrowth of algae) and physical disturbances such as dredging, anchoring, construction, and shading from manmade structures.	Prior to restoration, important to ensure that stressors (such as nutrient enrichment) are removed. Success is unlikely if the area is/has been for a long time devoid of seagrass. Light and sediment conditions are key factors. Protection of restored sites may be important to ensure survival and success.
Structural complexity (Box 3 & 4 in Figure 4.6)	High structural complexity. Seagrasses offer shelter for many fish, invertebrate and epiphytic species	Seagrasses should attract other species when meadows mature, and be sustained in the long-term through positive feedback mechanisms.
Diversity (Box 2 and 4 in Figure 4.6)	High associated biodiversity. Feedbacks and top-down controls are important for seagrasses. Seagrasses can grow intermixed with each other or with other plant species.	Ensure healthy populations of top predators, which control algal blooms (by reducing overfishing or fishing bans), and other structuring species (bivalves, infauna). Reintroduce important species if they have disappeared. Mixed meadows show facilitation of *Z. marina*, plant in mixtures and include pioneering species if possible.

3.3.1.2 North-East Atlantic (Norway) – Shallow hard – Kelp forests

The kelp species *Laminaria hyperborea* and *Saccharina latissima* (sugar kelp) are habitat building species, creating forests dominating the subtidal shallow (down to ~30 m) rocky coasts of the NE Atlantic. Kelp forests provide food, shelter and habitat for a large number of species, invertebrates in particular, but also fish, seabirds and sea mammals (e.g. Norderhaug et al. 2005, Christie et al. 2009, Leclerc et al. 2013). Kelp properties (e.g. density, growth, size and morphology) and the associated flora and fauna species vary with environmental conditions, such as wave exposure and ocean currents (e.g. Hurd 2000 and references therein, Wernberg & Thomsen 2005, Wernberg & Vanderklift 2010, Bekkby et al. 2014, Norderhaug et al. 2014). Some of the high primary production is consumed by secondary producers within the kelp forest, that are further transported through the food web to fish and sea mammals (Fredriksen 2003, Norderhaug et al. 2003, Christie & Norderhaug 2016). Kelp forests (an macroalgae in general) play a major role in the carbon cycle and store large amounts of carbon (Gundersen et al. 2010, Krause-Jensen & Duarte 2016). A large part of kelp produced carbon is exported to other ecosystems, such as deep and shallow seabed, as well as onto shore (Krumhansl & Scheibling 2012).

Dynamics – Kelp forests have high reproduction and growth rates. *L. hyperborea* kelp are long-lived (up to 21 years), with the most rapid lamina growth between December and June, the old blade being lost in spring or early summer (Kain 1971b). *S. latissima* are shorter lived perennials (maximum age 5 years), also with maximum growth rate in spring and early summer (Andersen 2013). Both kelp species have a complex life cycle including a heteromorphic alternation of generations; the long-lived diploid sporophyte which is the kelp plant you can see, and the microscopic haploid gametophytes (males and females), that lives on-noticed on the seafloor. The reproduction season is in winter, with production of zoospores that are released from the lamina, and that further develops into gametophytes, that through sexual reproduction produce the new sporophytes. The life cycle has implication for the restoration techniques need, and for timing of transplantation. High longevity implies a long time for achieving a recovered mature kelp forest community.

Connectivity – The *L. hyperborea* kelp forest in Norway occur in outer wave exposed areas along the whole coast, creating a rather connected band of kelp. The species produces a high number of propagules, that can be dispersed for several days with coastal currents (Reed et al. 1992). Hence, there is a high degree of connectivity among the kelp populations in Norwegian coastal waters, confirmed by genetic analyses (of both *L. hyperborea* and *S. latissima*, Evankow 2015). Grazing by sea urchins creates barren areas that fragmentise kelp populations in moderately wave exposed and sheltered areas in northern Norway, implying reduced connectivity between the kelp populations in these areas. The sugar kelp has a more restricted spatial distribution, and occur in more sheltered archipelagic areas than *L. hyperborea*. Although the species has high reproduction (Andersen 2013), the species is likely to have lower connectivity between populations than *L. hyperborea*. Additionally, in northern Norway there might be very long distances to nearest sugar kelp population in the barren areas, due to the lack of outer, non-grazed kelp forest areas as exist for *L. hyperborea*. The degree of connectivity has implications for the restoration success; shorter distances to natural "mother plants" will likely increase the success rate of restoration actions. Additionally, it will be easier to achieve donor plants that are genetically similar, and more likely to be adapted to the environmental conditions at the restoration site.

Spatial distribution – *L. hyperborea* grows on bedrock and large rocks and boulders in the wave exposed part of the NE Atlantic coast (Bekkby et al. 2009), from Portugal in the south (Kain 1971a) to the Murman coast in the north (Schoschina 1997). *S. latissima* may grow unattached on smaller rocks in sandy areas, as well as on boulders and bedrock in the more sheltered parts (Bekkby & Moy 2001). Along the Norwegian coast, *L. hyperborea* has been modelled to cover almost 6000 km^2, *S. latissima* about 2000 km^2 (Gundersen et al. 2010). The potential lost abundance of sugar kelp due to sea urchin grazing and turf algae are considered to be high (Gundersen et al. 2010). The distribution of kelp varies with environmental conditions, such as wave exposure and ocean currents (e.g. Bekkby et al. 2009, Bekkby and Moy 2011). The substrate preferences and the needed environmental conditions for the kelp species, are needed to take into account when selecting sites for kelp restoration.

Vulnerability/fragility – In the southern part of Norway, large areas of S. *latissima* kelp (80% in Skagerrak, 40% on the Norwegian West coast) have been lost due to eutrophication effects (Bekkby and Moy 2011, Moy and Christie 2012). In northern Norway, *Laminaria hyperborea* has been impacted significantly by the grazing of sea urchins (*Strongylocentrotus droebachiensis*, Norderhaug and Christie 2009). Gundersen et al. (2010) have modelled that approx. 2000 km^2 of the *L. hyperborea forests* have been grazed by sea urchins. Some of these areas are now recovering (Norderhaug and Christie 2009, Rinde et al. 2014), most likely due to a combination of temperature increase and increasing predatory (crab) pressure on the sea urchins (Fagerli et al. 2013, 2014). In these areas, the sea urchin *Echinus esculentus* has been found to graze on epiphytic algae on the stipe of the *L. hyperborea* kelp (Bekkby et al. 2014), probably reducing the ecological function of the kelp forest. About 7000 km^2 of S. *latissima* might have been lost due to grazing and eutrophication (Gundersen et al. 2010). The loss of kelp forests is a global phenomenon, and destructive grazing by sea urchins has been documented for many areas (Steneck 2002, 2004). Water quality, eutrophication and presence of sea urchins are factors that are needed to be considered when selecting sites for kelp restoration. *L. hyperborea* are harvested in Norway, and selection of restoration sites must also consider if the area is opened for kelp trawling. Areas in progress of natural recovery, should have high priority for being selected for restoration actions.

Structural complexity – In particular the *L. hyperborea* kelp forest have a high 3D complexity, with the up-right stipe that can be approximate 3 m long, and with a heterogeneous understory of smaller and younger plants. The sugar kelp creates a less structural complex 3D forest, by the slenderer stipe that more or less lies on the seafloor, creating to a lesser degree a habitat for other species. Both kelp species support complex food webs with a high number of species at different trophic levels, creating a resilient ecosystem. The kelp plants dampen wave exposure, creating stable and calm environment for the associated species The complexity can make it harder to succeed in restoring *L. hyperborea* compared to sugar kelp forests.

Diversity – Both *L. hyperborea* and *S. latissima* can create monospecific stands of kelp forests. They can also occur in mixed stands, in particular in deeper water in the wave exposed areas (where sugar kelp can find sufficient shelter for waves), but also in moderately wave exposed, shallow areas. Kelp forests have in general a high diversity of species (e.g. Steneck et al. 2002, Smale et al. 2013, Krause-Jensen & Duarte 2014). Due to the more complex structure of the *L. hyperborea* plant (in particular the up-right rigid stipe with suitable substrate for epiphytes, and the large complex holdfast), compared to the sugar kelp, *L. hyperborea* have a considerable higher diversity of associated flora and fauna. The higher longevity of *L. hyperborea* also allows for a longer time for being colonised by invertebrates and other algae species, increasing the difference in diversity between the two kelp species, and further increasing the risk of not succeeding to completely recover a mature *L. hyperborea* forest.

Table 3.3. Key features for the MERCES case study habitat *Laminaria hyperborea* kelp forests (shallow hard) in the Norwegian NE Atlantic and implications for restoration and thereby the chances of recovery (recovery potential). *Laminaria hyperborea* is the major forest building species at the wave exposed parts of the Norwegian coast. Table 3.4 shows the kelp forests dominating the sheltered and moderately exposed parts of the Norwegian coast.

Key features	Specific characteristics	Implications for restoration
Dynamics	High recruitment and growth rate. High longevity	● Restores quickly when sea urchins are removed (directly or by introducing predators such as crabs) ● Potentially high survival rate of transplanted kelp ● Transplanted kelp plants can quickly become spore donors to adjacent barren areas ● High longevity – might be difficult to achieve
Connectivity	High connectivity, high number of propagules	● High probability of recovery success through recruitment from nearby natural populations ● Easy access to genetically similar donor plants / transplants from nearby populations
Spatial distribution	Wide distribution in the wave exposed and moderately exposed areas. But preferences for certain substrate types.	● Restoration actions may be implemented at large spatial scales ● High probability of restoration success if substrate is available and sea urchins are removed
Vulnerability/fragility	The major threats for kelp are eutrophication, temperature increase and grazing by sea urchins. Recovery occur in areas with increasing crab abundance.	● High probability of restoration success if sea urchins are removed ● Crab predation (on urchins) increases the probability of restoration success ● Multiple stressors affect restored populations (incl. temperature) ● Areas in progress of natural recovery should be prioritised for kelp restoration
Structural complexity	High 3D complexity, with high abundance and diversity of associated flora and fauna	● Recovery of the structural complexity of the kelp forest (including variation in age and size), is important ● The less complex sugar kelp forest will be easier to recover than the more complex *L. hyperborea* kelp forest.
Diversity	High diversity (species, functional and genetic) of associated flora and fauna	● Recovery of the whole system, incl. associated flora and fauna, takes longer time than the recovery of the kelp, and will take longer time to achieve for L. *hyperborea* compared to sugar kelp.

Table 3.4. Key features for the MERCES case study habitat *Saccharina latissima* (sugar kelp) kelp forests (shallow hard) in the Norwegian NE Atlantic and implications for restoration and thereby the chances of recovery (recovery potential). *Saccharina latissima* is the major forest building species at the wave sheltered and moderately exposed parts of the Norwegian coast. Table 3.3 shows the kelp forests dominating the exposed parts of the Norwegian coast.

Key features	Specific characteristics	Implications for restoration
Dynamics	High growth rate, high turnover	• Restores quickly when sea urchins and turf algae are removed (sea urchins removed due to increased temperatures and increased predatory pressure, turf algae due to reduced eutrophication) • Potentially high survival rate if sea urchins are removed and the substrate is clean
Connectivity	High connectivity, high number of propagules, relatively high dispersal distance	• High probability of recovery success by natural recovery through recruitment from nearby populations
Spatial distribution	Wide distribution in the wave sheltered areas	• Restoration actions may be implemented at large spatial scales • High probability of restoration success if substrate is available and sea urchins and turf algae are removed
Vulnerability/fragility	Medium resistance and recovery, vulnerable to human activities in sheltered areas, incl. eutrophication and siltation	• High probability of restoration success if sea urchins and turf algae are removed and the substrate is clean • Crab predation (on urchins) increases the probability of restoration success in grazed areas • Multiple stressors affect restored populations (incl. temperature)
Structural complexity	Forest building kelp with a 3D complexity, relatively high associated flora and fauna	• Recovery of the whole system, incl. the associated flora and fauna, is important • Recovery of the whole system, incl. associated flora and fauna, takes longer time than the recovery of the kelp
Diversity	Relatively high diversity (species, functional and genetic) of associated flora and fauna	• Recovery of the whole system, incl. associated flora and fauna, takes longer time than the recovery of the kelp

3.3.1.3 Mediterranean Sea – Shallow hard – Macroalgal forests

Shallow and deep macroalgal assemblages, considering only *Cystoseira* species

Macroalgal forests such as kelps and fucoids are dominant habitat-forming species in rocky intertidal and subtidal habitats around all the Mediterranean coasts. Macroalgal forests are recognized hot spots of diversity, provide food and habitat to diversified assemblages of understory species and enhance coastal primary productivity. Macroalgal forests can thrive from the intertidal to the circalitoral. Macroalgal forests show a succession of different dominant species dwelling at each depth. The following chapters and the tables 3.5 and 3.6 discuss the key important, but generic features identified by WP1 participants in order to systematically assess the factors that are relevant to restoration and thereby the chances of recovery (recovery potential) for macroalgal forests.

Dynamics – Despite of the key role of macroalgae in coastal ecosystems, it is surprising how scarce our knowledge about most species and their population dynamics still are. Shallow-water species and most kelp species have population dynamics that highly depend on reproductive processes and growth rates. the recovery of fucoid populations can take decades, probably due to their poor dispersal ability and the slow population dynamics (slow growth and reproduction maturation), suggesting that fucoid populations may require further protection and their recovery may need restoration actions.

Connectivity – Using microsatellite markers, significant genetic structure was reported in *Cystoseira amentacea var. stricta* between nearby populations suggesting a low dispersal capacity of the species (Susini et al. 2007, Robvieux et al. unpublished). Microsatellites were developed in *Cystoseira tamariscifolia* (Engelen et al. 2017), nevertheless to our knowledge population genetics data are not yet available. In the most comprehensive study to date, Thibaut et al. (2016) demonstrated that populations of *Cystoseira amentacea* separated by 2.6 km in the bay of Marseilles (France) were significantly differentiated.

Spatial distribution – Macroalgal forests such as kelps and fucoids are dominant habitat-forming species in rocky intertidal and subtidal habitats around all the Mediterranean coasts. Macroalgal forests can thrive from the intertidal to the circalitoral. Macroalgal forests show a succession of different dominant species dwelling at each depth. Generally, community structure measures (i.e. diversity and species richness) increase, and community dynamics (i.e. productivity, turnover and growth rates) decrease, with increasing depth (e.g. Ballesteros 1989, 1991, Garrabou et al. 2002). Therefore, habitat features depend on the depth where macroalgae develop. In response to multiple stressors, including urbanization, eutrophication and increasing sediment loads in coastal areas, these habitats (shallow and deep) are being lost at alarming rates and manipulative experiments have demonstrated that these systems may switch towards the dominance of algal turfs if the macroalgal canopy is removed or damaged.

Vulnerability/fragility – Macroalgae in shallow and sheltered parts of coastal areas are subject to great pressure from various human activities as well as being at risk due to climate change. The decline or disappearance of forest building species from many coastal areas is leading to severe habitat transformations, with the loss of tri-dimensional structures. Loss of perennial macroalgae, either by natural or anthropogenic disturbances, generally results in barrens with an overall loss of biodiversity or an increase of filamentous turf algae. Nutrients, chemical pollution, from metals to several persistent organic pollutants (POP), coastal development and urbanization, frequentation, outbreaks of grazer populations or even natural storms are among the perturbations frequently associated with fragmentation and loss of *Cystoseira* populations. Climate change also influence marine macroalgae and their associated ecosystems. Besides global stressors, multiple other local stressors such as abandoned fishing gears (nets, trammel nets, threads) or trampling may threat local and restricted *Cystoseira* populations on a local scale.

Structural complexity – Macroalgae provide biogenic structure, food and shelter to diversified assemblages of understory species and enhance coastal primary productivity. In the Mediterranean coastal areas, the fucoid algae *Cystoseira* spp. form dense canopies able to maintain species rich understory assemblages of sessile and vagile invertebrates and smaller-sized algae by providing shade and reducing physical stress due to aerial exposure. The disappearance of *Cystoseira* always causes a consistent decrease in invertebrates' abundance. *Cystoseira crinita* and *C. balearica* forests have a high nursery value and the consequences of the alteration of this habitat on the recruitment of rocky reef fish assemblages are great. In fact, densities of several reef fish juveniles—particularly *Symphodus* spp.—have been found 9 to 12 folds greater in *Cystoseira* forests than in other erect, turf, barren habitats. The nursery value and the functional importance of Cystoseira forests suggest that their loss strongly affects the recruitment of littoral fishes in the Mediterranean Sea with serious consequences on the goods and services they provide. Clearly, the effects of canopies on other biodiversity compartments can be different across species: *Cystoseira compressa* has short fronds, so the understory environment can be limited compared to that provided by other congeneric species with larger fronds. The decline or disappearance of *Cystoseira* forests from many Mediterranean areas is leading to severe habitat transformations, with the loss of tri-dimensional structures. Loss of *Cystoseira*, either by natural or anthropogenic disturbances, generally results in the increase of turfs or barrens with an overall loss of biodiversity. A simple model suggested the existence of a critical threshold in the *Cystoseira*–turf system, with a tipping point at about 75% of canopy loss.

Diversity – Macroalgal forests are recognized hot spots of diversity and provide food and habitat to diversified assemblages of understory species and enhance coastal primary productivity (Sala & Knowlton 2006, Gianni et al. 2013). Some studies have detected the regression, and even disappearance of macroalgae forest related to increased pollution levels (e.g. Arevalo et al. 2007, Sales et al. 2011), habitat loss (due to coastal development and urbanization, e.g. Fraschetti et al. 2012, Perkol-Finkel & Airoldi 2010, Perkol-Finkel et al. 2012), natural events (Navarro et al. 2016), outbreaks of grazer populations (Sala et al. 1998, Hereu 2004, Gianni et al. 2013), invasive species such other macroalgae (competence) or rabitfish (grazing) (Scheibling & Gagnon 2006, Vergés et al. 2014) and climate change (Lima et al. 2007). Besides global stressors, multiple other local stressors such as abandoned fishing gears (nets, trammel nets, threads) (Capdevila et al. 2016) or trampling may threat local and restricted macroalgae populations.

Table 3.5. Key features for the MERCES case study habitat macroalgal forest (shallow hard) in the Mediterranean Sea and implications for restoration and thereby the chances of recovery (recovery potential). Only *Cystoseira* species is considered. This table presents the shallow part (<15 m depth), e.g. C. *mediterranea, C. amentacea, C. compressa, C. balearica, C. brachicarpa.* Table 3.6 shows the Mediterranean macroalgal forests in the deep parts.

Key features	Specific characteristics	Implications for restoration
Dynamics	Fast	● Short time scales
	Medium	● Medium time scales.
Connectivity	Medium	● Possible natural recovery
	Very Low	● Difficult natural recovery from neighbouring populations. ● Restoration actions at local spatial scales
Spatial distribution	Extended	● Implement restoration actions at large scales. ● Potential higher probability success.
	Restricted	● Local restoration actions at local scale. ● Potentially low success probability.
Vulnerability/ fragility	Medium	● Wider range of restoration sites are available.
	High	● Select sites were pressures are completely removed. ● Multiple global stressors can affect restored populations.
Structure complexity	High structure complexity	● Restoration actions focused on habitat forming species. ● Focus on large adult organisms to avoid long-term recovery.
Diversity	High diversity	● Focus on structural species to provide habitat for associated species. ● Difficult to return to the original assemblage.

Table 3.6. Key features for MERCES case study habitat macroalgal forest (shallow hard) in the Mediterranean Sea and implications for restoration and thereby the chances of recovery (recovery potential). Only *Cystoseira* species is considered. This table presents the deep part (>15 m depth), e.g. *C. spinosa, C. zosteroides.* Table 3.5 shows the Mediterranean macroalgal forests in the shallow parts.

Key features	Specific characteristics	Implications for restoration
Dynamics	Slow	● Long-time scales. ● Potential high survival rates.
Connectivity	Medium connectivity	● Possible natural recovery
Spatial distribution	Wide distribution but fragmented	● Implement restoration actions at large scales. ● Potential higher probability success.
Vulnerability/fragility	High	● Select sites were pressures are completely removed. ● Multiple global stressors can affect restored populations.
Structure complexity	High	● Restoration actions focused on habitat forming species. ● Focus on large adult organisms to avoid long-term recovery.
Diversity	High	● Focus on structural species to provide habitat for associated species. ● Difficult to return to the original assemblage

3.3.1.4 Mediterranean Sea – Shallow hard – Coralligenous assemblages

Coralligenous assemblages are hard bottoms of biogenic origin that are mainly produced by the accumulation of calcareous encrusting algae growing at low irradiance levels. Coralligenous assemblages harbour approximately 10% of the marine Mediterranean species, most of these associated species are long-lived algae and sessile invertebrates, many of which exhibit low growth and recruitment rates and belong to taxonomic groups such as sponges, corals, bryozoans and tunicates (Ballesteros 2006, Teixidó et al. 2011). The following chapters and Table 3.7 discuss the key important, but generic features identified by WP1 participants in order to systematically assess the factors that are relevant to restoration and thereby the chances of recovery (recovery potential) for coralligenous assemblages.

Dynamics – In general, coralligenous species display slow growth rates, between 0.1 and 4 cm per year (Coma et al. 1998, Cocito et al. 1999, Garrabou & Harmelin 2002, Teixidó et al. 2011, Linares et al. 2010, 2012a, Sartoretto & Francour 2012, Priori et al. 2013, Munari et al. 2013). This indicates that the potential life span of this species can easily reach many decades (Linares et al. 2007, Teixidó et al 2011). As a long-lived and slow-growing species, gorgonians and sponges display low recruitment rates (Cocito et al 1998, Linares et al. 2007, Teixidó et al. 2011, Linares et al. 2012a,b, Montero-Serra et al. 2015)

Connectivity – Several studies, mainly performed at local scales, suggest that the populations of different coralligenous species are mainly closed and that recovery from larvae coming from external sources may be limited. Among different taxa, there are several studies focusing on gorgonians; in contrast there is an important lack of knowledge about the connectivity patterns of sponges and bryozoans of coralligenous assemblages. While *Paramuricea clavata* and *Corallium rubrum* showed a significant genetic structure between populations separated by several meters (Costantini et al. 2007a,b, Ledoux et al. 2010a,b, Mokhtar-Jamaï et al. 2011, Arizmendi-Meija et al. 2015), *Eunicella singularis* and *Eunicella cavolini* showed significant differences between populations separated by > 10 km (Pey et al. 2013, Costantini et al. 2016, Masmoudi et al. 2016). In sponges, a significant genetic differentiation has been also observed at the lower spatial scale under survey (around 20 km) suggesting restricted gene flow and low recolonization capacities.

Spatial distribution – Coralligenous assemblages extend around all Mediterranean coasts with a bathymetrical distribution ranging from 20 to 120 m depth depending on the local environmental variables, mainly light conditions (Ballesteros 2006, Martín et al. 2014).

Vulnerability/fragility – Coralligenous communities are presently threatened by a combination of nutrient enrichment, invasive species, increase of sedimentation, mechanical impacts, mainly from fishing activities, as well as climate change (Ballesteros 2006, Balata et al. 2007, Garrabou et al. 2009, Piazzi et al. 2012). The fragility of coralligenous communities seems to be related to both the stability of the environment in which they have evolved and the low demographic dynamics of most coralligenous species. During the last decades, global stressors, such as climate change, are among the most concern threat for these communities. Coralligenous assemblages have been affected by several mass mortality events (in 1999, 2003 and 2006) related to unusual climatic anomalies in the NW Mediterranean Sea (Garrabou et al. 2009). Some invasive algal species (*Womersleyella setacea, Acrothamnion preissii,* *Caulerpa racemosa* v. *cylindracea* and *C. taxifolia*) can also pose a severe threat to these communities, either by forming dense carpets (i.e. physical barriers) or by increasing sedimentation (Cebrian et al. 2012, Linares et al. 2012a).

Structural complexity – The coralligenous bioconstruction is formed by the superposition of living calcareous organisms on dead skeletons of previous generations, creating a secondary hard substrate. Several coralligenous species are ecosystem engineer species which provide structure and biomass, increasing the flora and fauna associated. Sponges play a key ecological role, which is both functional and structural (Cerrano et al. 2006). Gorgonians provide a variety of habitats and refuges for several invertebrates. In addition, gorgonians seem to have a large effect on community structure modifying environmental conditions, through their physical presence and not their biological actions (Gili & Coma 1998).

Diversity – After the *Posidonia oceanica* meadows, coralligenous communities is one of the most important 'hot spot' of species diversity in the Mediterranean (Boudouresque 2004), with an estimate of the total number of species reaching to 1666 species (Ballesteros et al. 2006). Coralligenous communities contain a high number of species belonging to very diverse taxonomic groups as sponges, gorgonians, molluscs, bryozoans, tunicates, crustaceans or fishes among others. Several endangered Mediterranean species live in the coralligenous habitat, although none is exclusive to these assemblages.

Table 3.7. Key features for the MERCES case study habitat coralligenous assemblages (rocky hard) in the Mediterranean Sea and implications for restoration and thereby the chances of recovery (recovery potential).

Key features	Specific characteristics	Implications for restoration
Dynamics	Slow growth rates	● Need for long time scales ● Potential high survival rates
Connectivity	Low (based on few species)	● Difficult natural recovery from neighbouring populations ● Restoration actions at local spatial scales
Spatial distribution	Wide distribution across the Mediterranean	● Implement restoration actions at large spatial scales ● Higher probability of restoration success
Vulnerability/fragility	High to anthropogenic activities	● Select sites where pressures are removed ● Multiple global stressors can affect restored populations
Structural complexity	High 3D complexity	● Import to focus on habitat-forming species ● Focus on large adult organisms in order to avoid waiting for long-term recovery
Diversity	High diversity (species, functional and genetic diversity)	● Restoration action should priory on structural species maintenance to ensure habitat availability for accompanying species. ● Reaching pristine or reference conditions will be difficult, or may take a long time.

3.3.1.5 Azores – Deep sea – Coral gardens

Cold-water corals (CWCs) are amongst the most important ecosystem engineers in the deep-sea across the globe (Roberts 2009). The habitats formed by CWCs vary from *coral reefs,* formed mostly by Scleractinia species (stony corals), to dense mono- or multispecies coral aggregations known as *coral gardens,* where Alcyonacea (gorgonians and soft corals), Pennatulacea (seapens) Antipatharia (black corals) and Stylasteridae (hydrocorals) are the most conspicuous components (OSPAR 2010, Henry & Roberts 2014). Both CWC reefs and gardens provide complex three-dimensional structural habitat that support high levels of biodiversity by providing refuge, feeding opportunities, and spawning and nursery areas for a wide range of organisms, including commercially important fish species (Buhl-Mortensen et al. 2010, Pham et al. 2015). In the Azores, coral gardens are the most prominent habitat builders with more than twenty different types of coral gardens recorded for the region (Braga-Henriques et al. 2013, Tempera et al. 2013). In addition to their bioengineering role, coral gardens provide important ecosystem services such as carbon storage and nutrient remineralization (Thurber et al. 2014). The following chapters and Table 3.8 discuss the key important features identified by WP1 participants in order to systematically assess the ecological attributes that are relevant to restoration success and thereby recovery potential for coral gardens.

Dynamics – Key indicator species in cold-water coral gardens are slow-growing organisms with long life spans, especially with regards to gorgonians and black corals (Watling et al. 2011, Wagner et al 2012). Gorgonians have linear extension growth rates of 0.44-2.32 cm per year and axis radial growth rates of 0.05-0.44 mm year^{-1}, with ages spanning from 30 to more than 400 years (reviewed by Watling et al. 2011). Deep-sea black corals are generally at the end of the spectrum of slow growing organisms with radial growth rates 0.002-0.066 mm per year (no estimates of linear extension growth rates) with estimated ages in the range of nearly hundreds to thousands of years in the Azores and other regions (82-4000 years: Sherwood & Edinger 2009, Roark et al. 2009, Carreiro-Silva et al. 2013). Coral growth rates may greatly depend on abiotic and biotic factors such as temperature, current, turbidity, ocean chemistry and food supply (Roberts 2009) and therefore are dependent on local environmental conditions at different spatial scales. Currently no growth rates estimates are available for most of octocoral species in Azores coral gardens and similarly current knowledge on the reproductive biology of these organisms is also still very limited. CWCs reproduce mainly sexually, through the production of gametes (Watling et al. 2011). Studies on the reproductive biology of black corals and gorgonians in the Azores, show that reproduction generally involves colonies of separate sexes (gonochorism), with the release of gametes in the water column where fertilization occurs externally (broadcast spawning) (Rakka et al. 2016, Rakka & Carreiro-Silva unpublished data). Gorgonians showed female skewed sex ratios, low fecundity (5-10 oocytes per coral polyp) and a continuous reproductive cycle, with 2-3 spawning events per year. Observations in the field and laboratory also suggest that asexual reproduction (fragmentation, fission, polyp expulsion) may play an important role in the reproductive ecology of CWCs especially under stressful conditions, although this has been rarely reported in the literature, especially for gorgonians (e.g. Parker et al. 1997, Waller et al. 2005).

Connectivity: Cold-water coral population's connectivity depends on the biological traits of their larvae and on the dispersal properties of the surrounding environment. However, information on larval biology, behaviour and physiological requirements, all of them influencing potential larval duration, dispersal distances, and connectivity patterns are unknown for most CWC species, except for a few studies on the reef-building coral *Lophelia pertusa* (Brooke & Järnegren 2013, Larsson et al. 2014) and soft corals (e.g. *Gersemia fruticosa* and *Duva florida*, Sun et al. 2011). CWC genetic connectivity studies have varied from large scale across thousands of kilometres (e.g. NW Atlantic seamounts: Thoma et al. 2009, Southern Ocean seamounts: Miller and Gunasekera 2017) to small-scale studies of few hundred metres or kilometres (Baco & Shank 2005, Dahl et al. 2012, Cardona et al. 2016). These studies revealed differing connectivity patterns depending on the coral group or species under study, with high genetic connectivity suggested for antipatharians and gorgonians across seamounts of the NW Atlantic (Thoma et al. 2009) and for the solitary coral *Desmophyllum dianthus* across seamounts in the Southern Ocean (Miller & Gunasekera 2017). Other studies showed genetic differentiation among some seamount populations of the gorgonian *Corallium lauuense* in Hawaii (Baco & Shank 2005), the scleractinian *Lophelia pertusa* in North East Skagerrak, Norway (Dahl et al. 2012) and the black coral *Leiopathes glaberrima* in the Gulf of Mexico (Cardona et al. 2016). The scleractinian *Solenosmilia variabilis* represents an extreme case of low genetic connectivity with negligible dispersal of sexually produced larvae resulting in isolated populations (Miller & Gunasekera 2017). For this species asexual reproduction appears to be main reproductive mode. At present, connectivity studies of important habitat forming CWC in the Azores and elsewhere in the Mediterranean and/or NE Atlantic (e.g. the black coral *Leiopathes glaberrima* and the gorgonians *Callogorgia verticillata* and *Acanella arbuscula*) are underway under the scope of the project ATLAS – "A Trans-ALantic Assessment and deep-water ecosystem-based Spatial management plan for Europe". The objective is to provide information on the connectivity patterns of key Vulnerable Marine Ecosystems (VME) indicator species across a wide range of sensitive Atlantic ecosystems to understand the vulnerability of genetic resources to N Atlantic circulation changes and human activities.

Spatial distribution – Coral gardens are widely distributed in deep-sea areas of the North East Atlantic and Mediterranean (Davies et al. 2017). Although the Exclusive Economic Zone (EEZ) around the Azores expands for about 1 mill. km^2, the area potentially suitable for CWC in general, and coral gardens in particular, is extremely small (less than 2%). Coral gardens are mainly found in areas of hard substrate and high current flow in seamounts and island slopes, typically below 200 m depth, although some coral species, such as the black coral *Antipathella wollastoni*, can occur as shallow as 20 m deep (Braga-

Henriques et al. 2013, Tempera et al. 2013, Rakka et al. 2016). Because of the particular conditions necessary for their occurrence, coral garden habitats generally cover small and fragmented areas. Know coral garden habitats in the Azores occur predominantly between 300 and 900m depths, in areas recognized as important bottom fishing grounds (Braga-Henriques et al. 2013).

Vulnerability/fragility – Major human activities impacting coral gardens, over their wide distribution range, include commercial bottom fisheries, hydrocarbon exploration and extraction, potential development of Blue Growth activities such as bio-prospecting and deep-sea mining, as well as global ocean change including warming and acidification (Ragnarsson et al. 2017). At a global scale, bottom trawl fishing is considered to be the major pressure impacting CWCs, often resulting in the removal of entire communities (Clark et al. 2016). In the Azores, bottom trawling and deep-sea netting are forbidden (European Council Regulation [EC] No. 1568/2005 of 20 September 2005, Santos et al. 2009) and therefore commercial bottom fisheries are instead dominated by hook-and-line fisheries, which have demonstrated to have reduced impact on coral communities compared to bottom trawling due to the reduced bycatch of CWCs and limiting additional damage to benthic communities (Pham et al. 2014a). However, longline fishing impacts organisms with a complex morphology, thereby having an unbalanced impact in the ecosystem which might eventually promote long-term shifts in community structure if not effectively managed. Higher vulnerability to longline fishing of large taxa with complex morphologies, i.e. a great portion of gorgonians and black corals in coral gardens, is of particular concern because these are generally long-lived species with very slow growth rates (see section above). Removal of such vulnerable organisms may eventually threaten their population health since growth and recruitment may be outbalanced by the amount removed and population recovery is highly unlikely (Pham et al. 2014a). Indeed, CWC resilience to damage by fisheries or other human activities is perceived as very low because of their life history characteristics and discrete habitat, which has resulted in coral gardens' being listed as vulnerable marine ecosystems (VME´s) (UNGA 2007, OSPAR 2010).

Structural complexity – Coral gardens provide tri-dimensional complex habitats and add functional capacity to the surrounding deep-sea environment, which are used by a high number of associated species (OSPAR 2008). Indeed, conspicuous components of these habitats are tall and arborescent gorgonian and black corals (up to 2 m in height and 1 m in width), which have led to a recent analogy of their dense populations as "animal forests", comparable to terrestrial forests in complexity, biodiversity, and structuring role (Rossi et al. 2017). Their complex structure offers refuge, source of food, spawning and nursery areas for a high variety of sessile and vagile organisms, including commercially important fish species (Buhl-Mortensen et al. 2010, Pham et al. 2015).

Diversity – The Azores is considered a hotspot of cold-water coral biodiversity in the NE Atlantic, with more than 150 species described to date (Braga-Henriques et al. 2013). The highest known species richness is of Alcyonacea (gorgonians and soft corals) representing about 56.6 % of know CWC species, followed by Scleractinia (24.2 %), Antipatharia (10.2 %) and stylasterids (9.0 %). Diverse assemblages (> 20 types) of mono- and multi-specific coral gardens are present in the region, some of these forming unique coral species associations that have not been recorded elsewhere in NE Atlantic (Tempera et al. 2013, Davies et al. 2017). Most CWC host a variety of associated fauna, including hydroids, sponges, bryozoans, zoanthids, polychaetes, ophiuroids and crinoids, gastropods, bivalves, and small anthozoans (Buhl-Mortensen et al. 2010). While no attempt has been made to quantify species richness of fauna associated to coral gardens, these numbers should not be far from those reported for *Lophelia pertusa* reefs (2704 worldwide species: Roberts & Cairns 2014), emphasising the importance of these habitats as supporting biodiversity. No data is available in terms of genetic diversity.

Table 3.8. Key features for the MERCES case study habitat cold-water coral gardens in the Azores and implications for restoration and thereby the chances of recovery (recovery potential).

Key features	Specific characteristics	Implications for restoration
Dynamics	Most species at the far end of the slow growth rates and high longevity spectra	• Need for extremely long time scales • Natural (or spontaneous) regeneration of similar communities unlikely due to varying responses of individual native species • Combination of restoration approaches will be necessary (natural regeneration, assisted regeneration and reconstruction)
Connectivity	Low fecundity and larvae dispersal (based on few species)	• Difficult natural regeneration from neighbouring populations • Assisted regeneration and reconstruction actions (i.e. active restoration) needed at local spatial scales • Focus on adult organisms to increase reproductive output and increase chances of population recovery
Spatial distribution	Widely distributed but patchy or fragmented across the Azores	• Combination of restoration approaches will be necessary; natural regeneration at large scales, assisted regeneration and reconstruction at smaller scale
Vulnerability/fragility	High to anthropogenic activities	• All major threats major will have to be removed (e.g. bottom fisheries) or mitigated (e.g. climate change) • Multiple global stressors can affect restored populations
Structural complexity	High 3D complexity	• Important to focus on habitat-forming species • Focus on adult organisms in order to avoid waiting for long-term recovery
Diversity	High diversity (species, likely also functional and genetic)	• Active restoration activities should focus on structural (3-dimensional) species to provide habitat for other associated species and therefore contributing to restore community diversity and ecosystem services • Active restoration activities will unlikely regenerate exactly the diversity of original assemblages due to varying responses of individual native species

3.3.1.6 Mediterranean basin and Central-Northern Atlantic - Deep-sea bottom communities

This text covers the different deep-sea habitats open slopes, submarine canyons, seamounts and deep-sea basins. The continental *slope* represents the connection between the continental shelf and the deep basin plains. It is characterized by a constant flux and change and it is strongly influenced by a current flow, seabed character and sediment instability (Danovaro et al. 2010). A *submarine canyon* is a steep-sided valley cut into the seabed of the continental slope, sometimes extending well onto the continental shelf, having nearly vertical walls. *Submarine canyons* are major topographic systems that enhance the heterogeneity of continental slopes (Levin et al. 2010). *Seamounts* are a mountain rising from the ocean seafloor that does not reach to the water's surface. It is estimated that there are ca 33 000 seamounts (with elevation >1000 m, Ramirez-Llodra et al. 2010a, Harris & Whiteway 2011, Yesson et al. 2011, Beaulie et al. 2015, Rogers et al. 2015). *Deep-sea basins* are plains on the deep ocean floor, usually found at depths between 3000 and 6000 m, lying generally between the foot of a continental rise and a mid-ocean ridge. Deep-sea basins represent the largest biome on our planet, covering 75% of the ocean floor (Danovaro et al. 2014). The following chapters and Table 3.9 discuss the key important, but generic features identified by WP1 participants in order to systematically assess the factors that are relevant to restoration and thereby the chances of recovery (recovery potential) for deep-sea bottom communities.

Dynamics – Different components of the benthic biota show different life cycles and strategies that can contribute in influencing their spatial patterns along the bathymetric gradients of the *open slopes* (Danovaro et al. 2009a, van der Grient & Rogers 2015). *Submarine canyons* are complex features characterized by elaborate patterns of hydrographic flow, sediment transport and accumulation, enhancing locally primary productivity and particulate matter concentrations (Skliris & Denidi 2006, Palanques et al. 2008, Pham et al. 2014b, Puig et al. 2014, Amaro et al. 2015). The variation in the frequency of these events and the pulses of material and energy influence the structure and functions of the benthic assemblages (Danovaro et al. 2009b, Bianchelli et al. 2010, Vetter et al. 2010, Amaro et al. 2016), which may create hotspots of biomass and biodiversity (Tyler et al. 2009). The different functional diversity and feeding strategies of meio-, macro- and megafauna can be responsible for the differences in abundance and biomass (van der Grient & Rogers 2015). *Seamounts* are often highly productive ecosystems and may play an important role in patterns of marine biogeography (Staudigel et al. 2006). The enhanced local primary and secondary production, nutrients and faunal (fish and zooplankton) standing stocks can influence the abundance and community structure of benthic components (Danovaro et al. 2009c, Pusceddu et al. 2009). *Deep-sea basin* species show slow growth rate and late maturity (McClain et al. 2012). Recent evidence has suggested that this ecosystem is much more temporally and spatially variable than previously thought, with potentially important implications for benthic abundance and biodiversity patterns (Lampitt et al. 2010, Pusceddu et al. 2010, 2013, Rex & Etter 2010, Sevastou et al. 2013).

Connectivity – The portion of the *open slopes* investigated so far is still considered “minimal”, as reported by Rogers et al. (2015). However, an increasing number of studies suggests that it is difficult to predict the spatial distributions of deep-sea benthos using a limited set of variables (Danovaro et al. 2009c). This issue is practically unknown for soft bottom fauna in *submarine canyons*. The connectivity of *seamount* populations has been considered primarily in the context of seamounts resembling island systems with elevated levels of endemism. Most of the studies on the genetic connectivity of seamount populations have been undertaken on commercially fished species. These studies have generally shown patterns of genetic homogeneity at oceanic or at regional geographic scales among populations sampled on seamounts. However, at the regional scale, genetic differentiation has been identified between populations of fish and cephalopod species located on the continental margin of Europe and the Azores Islands on the Mid-Atlantic Ridge (Aboim et al. 2005, Stockley et al. 2005). For non-commercial seamount invertebrates, there are also mixed patterns of genetic connectivity. Recent published studies suggest the presence of largely self-recruiting populations, with occasional long-distance dispersal. Genetic studies provide evidence that populations of organisms on seamounts demonstrate a large variation in distances over which dispersal may occur. Life history clearly influences connectivity, and complex hydrography around seamounts and/or larval behaviour can lead to larval retention and less consistent patterns of connectivity compared to deeper waters, where currents are considered more uniform and predictable (Clark et al. 2010 and references therein). The increasing use of physical oceanographic modelling, predictive habitat mapping, ground-truth surveys and identification of different biogeographic provinces have all contributed to an improved understanding of the scales of genetic connectivity in the *deep sea basins*. This understanding arises from new knowledge about species-specific habitat requirements, distributions and types of substrata within habitat types, as well as factors such as currents and specific topography that may act as a barrier to gene flow. It has been demonstrated that distinctive environmental conditions may act as barriers to gene flow (Watling et al. 2013). Despite the recognition of the importance of connectivity and the need to identify source and sink populations, not many genetic connectivity studies have been published so far for deep-sea ecosystems. Thus, further studies are needed to determine if a general pattern of genetic structure exists and identify causative agents (factors) as barriers to gene flow amongst deep-sea taxa.

Spatial distribution – For *open slopes*, the decrease of benthic abundance and biomass with increasing water depth is particularly evident for macrofauna and megafauna and to a lesser extent for meiofauna (Rex et al. 2006, Wei et al. 2010, Gambi et al. 2010, Sevastou et al. 2013, van der Grient & Rogers 2015, Rogers et al. 2015). Investigations carried out on smaller benthic components (e.g. bacteria and protozoa) reveal barely decreasing or invariant bathymetric patterns (Danovaro et al. 2002, Rex et al. 2006, Deming & Camperter 2008, Wei et al. 2010, Sevastou et al. 2013). The decrease of benthic faunal abundance and biomass with increasing water depth is explained with the exponential decrease in organic matter supply

(Jones et al. 2014). *Submarine canyons* and *seamounts* are known to support special biological communities, with high levels of endemic species and their spatial distribution is influenced by the spatial distribution of food sources and habitat heterogeneity (Samadi et al. 2006, Zeppilli et al. 2013, 2016, Danovaro et al. 2014, Amaro et al. 2016, Gambi & Danovaro 2016). Several mechanisms have been invoked to explain the spatial patterns of benthic abundance and biodiversity of *deep-sea basins*: sediment grain size and substrate/habitat heterogeneity (Danovaro et al. 2010, Bongiorni et al. 2010, McClain & Barry 2010, Vanreusel et al. 2010), productivity (Smith et al. 2008, Lampitt et al. 2010, Tittensor et al. 2011, McClain et al. 2012), food resources (Danovaro et al. 2008b, Gambi & Danovaro 2006, Gambi et al. 2010, 2014, Sevastou et al. 2013), oxygen availability (Diaz & Rosemberg 1995), water currents (Lambshead et al. 2001) and occasional catastrophic disturbances (Levin et al. 2001, Pusceddu et al. 2010, 2013). Nonetheless, all of these factors are subjected to strong scientific debate because they are often site-specific and constrained by local (or regional) conditions (Levin et al. 2001).

Vulnerability/fragility – The most immediate threats to for *open slopes* are related to several anthropogenic activities that include fishing, oil and gas exploitation, cable laying, pipeline construction, underwater noise and water pollution from shipping routes, waste dumping, drill cuttings from mining activities, and pollution from terrestrial sources (Armstrong et al. 2012, 2014, Benn et al. 2010, Ramirez-Llodra et al. 2011). These threats can have different impacts on the benthic components (microbes, meio-, macro- and megafauna) and can differently compromise their dynamics, connectivity, spatial distribution, structural complexity and diversity. The negative effects of the disposal of litter and waste, fishing (trawling and long lining), oil and gas exploration and extraction have been documented at global ocean scale (Ramirez-Llodra et al. 2011) but also along the northern-western continental margins of the Mediterranean basin (Ramirez-Llodra et al. 2010b, Pusceddu et al. 2014, Pham et al. 2014 a,b). Recent investigations on *submarine canyons*, carried out in different Mediterranean canyons (La Fonera, Cap de Creus, Blanes, Palamos, Rose) located along the Catalan and Iberian continental margins, reveal that bottom trawling has many impacts on marine ecosystems, including seafood stock impoverishment, sediment resuspension, benthos mortality with the collapse of benthic biodiversity and ecosystem functions, with potential consequences on the biogeochemical cycles (Ramirez-Llodra et al 2010b, Puig et al. 2012, Martin et al. 2014, Pusceddu et al. 2014). Another threat on soft bottom communities is the presence of a large amount of waste and litter as documented in some canyons located in the northern-western Mediterranean continental margins (Cassidaigne & Lacaze-Duthiers canyons, Fabri et al. 2014). Major concerns are related to *seamount* fishing, especially trawling that physically removes the soft bottom, destroys reef-building organisms (Williams et al. 2010), disturbs the abundant seamount filter feeding communities by sediment re-suspension (Clark et al. 2010) and selectively removes long-lived commercially valuable fish species that are extremely vulnerable to heavy fishing (Morato et al. 2006, Puig et al. 2012). Recently, seamounts have been investigated from a geological point of view, as the presence of hydrothermal and metal deposits have been reported on the top of these systems (Petersen et al. 2014). The top of the Palinuro seamount (Tyrrhenian Sea, Central Mediterranean) has been repeatedly affected by geological investigations based on rock-drilling and dredging and the presence of halls is still visible after several years (Petersen et al. 2014). These impacts can compromise dynamics, biodiversity, spatial distribution and connectivity of soft-bottom communities associated to seamounts also taking into account that they show a very slow recovery after the end of impacts (Clark et al. 2010). The threats on *deep-sea basins* are related to oil and gas exploitation, cable laying, pipeline construction, underwater noise and water pollution from shipping routes, waste dumping, and drill cuttings from mining activities (Armstrong et al. 2012, 2014, Benn et al. 2010, Ramirez-Llodra et al. 2011, Jones et al. 2017). Many deep-sea activities are likely to increase globally over the next decades (Ramirez-Llodra et al. 2011), such as mining activities for deep-sea resources like rare earth metals (e.g. gold, copper, zinc and cobalt), and hydrocarbons (e.g. oil, gas, and gas hydrates) which will pose new potential threats to the deep-sea communities (Kato et al. 2011, Ramirez-Llodra et al. 2011, Jones et al. 2017). Recently, the presence of marine litter has been documented in different deep-sea sites from the Western to the Eastern Mediterranean basin (Ramirez-Llodra et al. 2013).

Structural complexity – Within the various deep-sea habitats, structural complexity varies depending on geological/topographical structure, biological/biogenic features and occurrence of geophysical events, increasing heterogeneity at smaller scales and resulting in rich biological communities (Gage 1996, Levin et al. 2001, Tselepides and Lampadariou 2004, Samadi et al. 2006, Vanreusel et al. 2010, Fernandez-Arcaya et al. 2017). *Open slopes* offer important ecosystem goods and services such as nutrient cycling, biodiversity, biological resources (finfish and shellfish), and cultural services for educational and scientific point of views (Armstrong et al. 2010, 2012, Rogers et al. 2015). Habitat heterogeneity may create hotspots of benthic biomass in *submarine canyons* (Tudela et al. 2003, Company et al. 2008, Tyler et al. 2009, Amaro et al. 2010, De Leo et al. 2010, Cunha et al. 2011). This can enhance the local fishery production on species of commercial interest (i.e. *Bathypterois mediterraneus* and deep-sea red shrimp *Aristeus antennatus*, D'Onghia et al. 2004, 2009, Sardà et al. 2009). *Seamounts* comprise heterogenous features hosting variable communities over large spatial scales and they are considered hotspots of biodiversity (Würtz & Rovere 2015). They offer important ecosystem goods and services such as biological resources, nutrient cycling, biodiversity, habitat, water circulation and exchange, and cultural services for education and science (Rogers et al. 2015). *Deep-sea basin* ecosystems offer several direct and indirect benefits to human well-being (Armstrong et al. 2012), including oil, gas, mineral, and living resources, chemical compounds for industrial, biotechnology, and pharmaceutical uses; gas and climate regulation; waste disposal and detoxification; CO_2 capture and storage; the passage of trans-ocean communication cables; and education and scientific research (Van Dover et al. 2014).

Diversity – Looking at *open slopes*, benthic biodiversity shows a more complicated pattern with depth exhibiting a peak of diversity often occurring at mid-slope depths before declining from the continental slope to the abyssal plains (Rex & Etter 2010). This is not a universal pattern with exceptions documented in various regions related to some cases to surface primary production (Danovaro et al. 2002). A unique, general driver to explain spatial patterns in deep-sea biodiversity measures has not been identified. Food supply almost certainly plays a role in driving the biodiversity pattern but other factors can be important such as sediment heterogeneity, level of natural disturbance, speciation and extinction (Rex & Etter 2010). This variety of factors is not surprising, considering the multiplicity of interactions among "local" ecological characteristics, environmental factors, and topographic and textural conditions in different slope environments (Narayanaswamy et al. 2013). The *submarine canyons* show a wide variety of biodiversity levels, trophic interactions and ecosystem functions, within each benthic components from microbes to megafauna (Danovaro et al. 2009b, Tyler et al. 2009, Bianchelli et al. 2010, De Leo et al. 2010, Cunha et al. 2011, Duros et al. 2011, Ingels et al. 2011, Paterson et al. 2011, Ingels et al. 2013, Ramirez-Llodra et al. 2013, Schlining et al. 2013, De Leo et al. 2014, Leduc et al. 2014, Ramalho et al. 2014, Amaro et al. 2010, 2015, Gambi & Danovaro 2016). Canyons are generally characterized by the presence of high level of endemism and biodiversity is influenced by the high habitat heterogeneity along the main axis and the walls of the submarine canyons. *Seamounts* are also known to play important roles in ocean biodiversity while also acting as centres of speciation, refuges for relict populations, and stepping-stones for trans-oceanic dispersal (George & Schminke 2002, Worm et al. 2003, Clark et al. 2010). A global-scale study based on *deep-sea basin* sites across all oceans, including the Mediterranean Sea, reports that that deep-sea ecosystem functioning is positively exponentially related to deep-sea biodiversity (Danovaro et al. 2008b). This relationship suggests that also a minor biodiversity loss in deep-sea ecosystems might be associated with exponential reductions of their functions (Danovaro et al. 2008a).

Table 3.9. Key features for the MERCES case study habitat deep-sea bottom communities in the Mediterranean basin and Central-Northern Atlantic and implications for restoration and thereby the chances of recovery (recovery potential).

Key features	Specific characteristics	Implications for restoration
Dynamics	Slow/Fast growth rates in relation to the different trophic groups (micro-, meio-, macro- and megafauna)	● Potential high survival rates for some groups and low survival rates for others
Connectivity	Scantly known due to sampling limitation; the spatial scale of ecosystem networks and characteristics of ecological and genetic connectivity are poorly; spatial and temporal dynamics act at large spatial scale	● Difficult to assess; ● It is challenging to understand how well a restoration effort fits into large landscape
Spatial distribution	Scantly known due to sampling limitation; some taxonomic groups endemic to deep-sea ecosystems have patchy distributions, high spatial variability driven by local variability	● Difficult to assess; ● Pilot studies should be performed at larger spatial scale
Vulnerability/ fragility	High to anthropogenic activities; external threats (e.g. global changes in ocean circulation resulting from a warming climate) impact the health and integrity of deep-sea ecosystems; pre-disturbance baselines lacking	● Remove impacts and major pressures; ● Changes in ecosystem functioning; ● Difficult to avoid or minimize external threats through restoration efforts, due to the physio-chemical connectivity of deep-sea ecosystems resulting from ocean circulation
Structural complexity	Habitat-forming species (e.g. corals) can host an associated fauna of diverse benthic invertebrate taxa	● Important to focus on habitat-forming species to enhance the biodiversity and reproductive success of associated invertebrates
Diversity	High diversity (taxonomic, functional and genetic), endemism; some indigenous taxa present low abundance in the deep sea	● Difficult to return to the original assemblages; it may be more practical to focus on restoring functional groups (e.g. suspension feeders, deposit feeders, size groups, etc.) rather than species; however, this could change community structure and species composition and provoke an over-simplification of structure and diversity

4. Discussion

4.1. The catalogues

4.1.1 The Habitats catalogue

The Habitats catalogue covers a considerable variety of sources in terms of different geographical areas, habitat types and ecological features. The higher proportion of entries from the Mediterranean Sea and the North-East Atlantic Ocean could be attributed to (a) multiple entries in the catalogue (i.e. one specific source may provide maps for multiple habitats, or provide maps for the distribution of a specific habitat in several sub-regions), (b) a higher availability of map resources as a result of more intensive research efforts (and funding) invested to date in specific sub-regions, (c) a higher variability in habitat types within some specific regions. Trends can also be seen within regional seas, within the Mediterranean Sea for example, there is an eastward declining trend of reported deep-sea habitat maps in the catalogue, possibly as a result of a higher number of existing studies towards the western basin.

The results of the systematic review revealed differences in habitat type records between sea basins and MSFD regions or sub-regions, which, to a certain extent, may reflect the habitat heterogeneity between different biogeographical regions/sub-regions. Some notable examples of sublittoral soft and hard substrate habitats are the meadows of the Mediterranean endemic seagrass *Posidonia oceanica* and the coralligenous assemblages, respectively, both of which were represented only by Mediterranean catalogue entries. On the other hand, the majority of entries for *Zostera* seagrass meadows and maerl beds were derived from North-East Atlantic map sources.

The dominance of sublittoral soft and deep-sea habitats in the catalogue can be viewed as an indication of where research efforts and stakeholder focus has been placed within the last few decades. A conservation focus can also be seen from the high percentage of the catalogue entries which cover map sources of Priority and Protected Species/Habitats as defined by the relevant EU Nature Directives and international legislations (e.g. 92/43/EEC and Barcelona Convention) and/or as Sensitive habitats/VMEs, as defined by STEFC and FAO respectively.

A high number of entries was sourced from project reports on regional scales (broad-scale entries were derived almost exclusively from online sources and websites, e.g. Figure 4.1 and 4.2), highlighting that grey literature constitutes a precious information source. However, there was found to be a lack of accessible georeferenced information (such as GIS rasters or shapefiles), limiting the possibility of data extraction and further use of habitat inventory data (e.g. for conservation planning initiatives or for compiling synthetic maps). Furthermore, the catalogue does not fully cover all available map resources at small scale (e.g. small Marine Reserves or individual bays) but mainly includes maps documenting habitats at the regional or national level, suggesting that effort should also be placed in habitat mapping at finer scales.

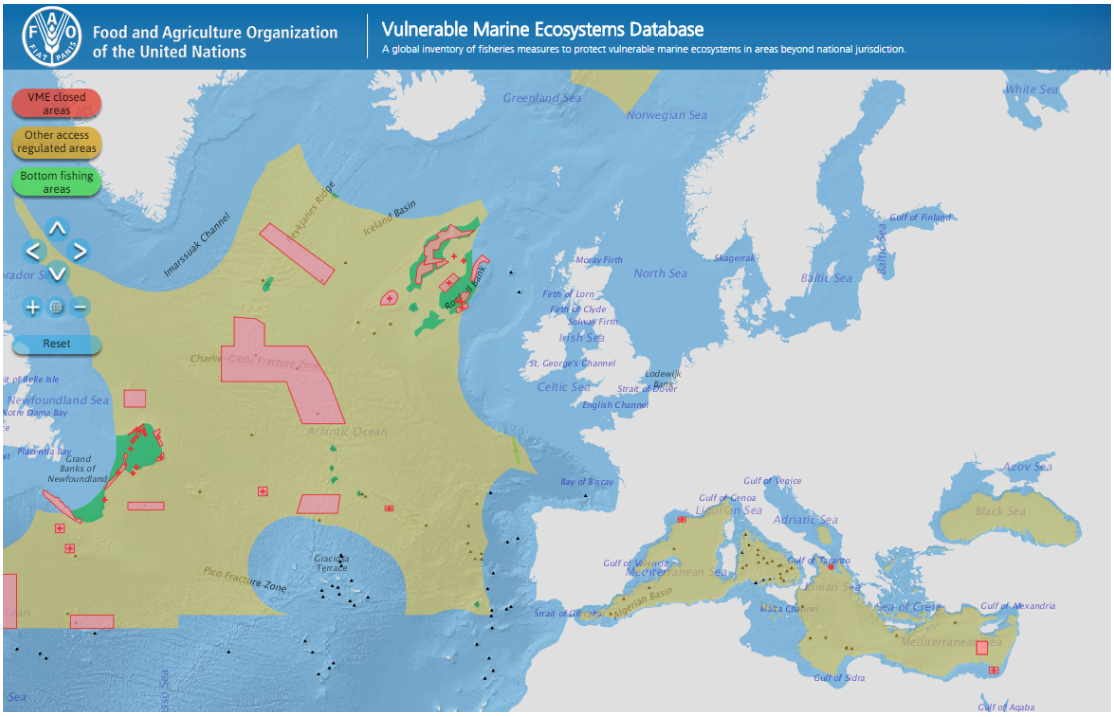


Figure 4.1. The Vulnerable Marine Ecosystems (VME) database by FAO includes spatial information for closures areas aiming at protection of VMEs from significant adverse impacts from Deep-sea fisheries (from www.fao.org/in-action/vulnerable-marine-ecosystems/en)

Natural changes in habitats are generally perceived to be slow; thus, policy acknowledges that habitat monitoring does not need to have a high frequency and is often in a 3-6 years cycle (e.g. MSFD, IMAP). The habitats in the catalogue have not all been concurrently mapped and very few map sources were digitally published in the 1990's (only 4) with the majority being produced after 2000. This is possibly related to the fact that pre-1990's habitat maps have not been digitized and/or are not publicly available through online data search tools. In the near future, it is expected that many more resources will be available through coordinated implementation of current EU environmental Directives while EMODnet will increase in resolution and feature content. It is also expected that there will be a general trend towards more open access georeferenced data (e.g. Horizon 2020 projects).

4.1.1.2 Map scale and availability

The EMODnet Seabed Habitats map is a major source to the information on habitat maps. EMODnet Seabed Habitats is based largely on modelled and interpolated data and so at the fine scale lacks accuracy, precision and resolution, limiting local use. Information levels are variable across the European Seas because of basic data availability – habitat mapping has been much more advanced in northern and western Europe than southern and eastern Europe (Figure 4.2, showing two parts of the European map on the same scale). This trend holds also true in most cases when moving from shallow to deep waters.

One of the main issues concerning any map is how good or reliable it is, which in many cases depends upon how it will be used. For example, broad scale maps are often intended to be used as indicative maps, having low resolution and accuracy. They may contain a high level of modelled/predicted data with a high degree of interpolation between data points. Fine scale maps may have more continuous data, ground-truthed with less interpolation to fill in blank areas. All maps have questions of accuracy, precision, scale and resolution. Accuracy relates to how accurately the map represents the features present, precision in that the features are correctly geo-positioned and resolution as to how much detail is given in the map.

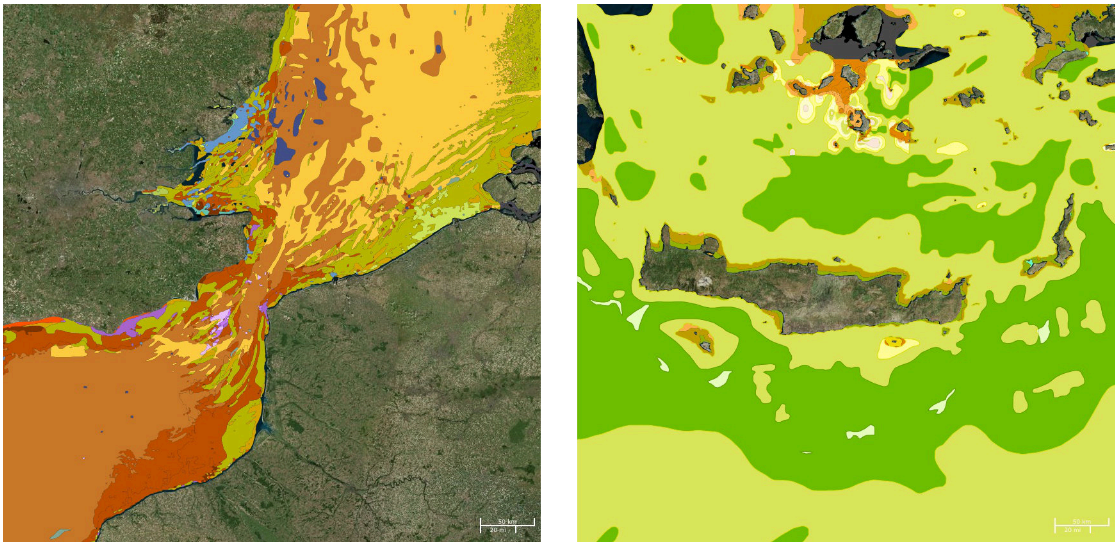


Figure 4.2. EMODnet broad-scale seabed habitat map for Europe (EUSeaMap, www.emodnet.eu/seabed-habitats) according to the EUNIS habitat classification, for the English Channel in the North-Eastern Atlantic (left) and the Sea of Crete in the South-Eastern Mediterranean Sea (right) (from online viewer www.emodnet.eu/seabed-habitats).

4.1.2 The Degraded habitats catalogue

The detailed search for maps on degraded habitats yielded a lesser number of map resources compared to those for the existing habitats. This conclusion is in accordance with the recent report of the European Environmental Agency (EEA 2015) on the "State of Europe's Seas", showing that a high percentage of European seabed habitats are still not assessed in relation to their status (Figure 4.3). To date, there is not a good global understanding of habitat degradation due to data gaps concerning the past/current status of several habitat types (e.g. deep-sea habitats). For instance, several types of marine habitats that were assessed as Vulnerable or Near Threatened under recent Red List Habitats assessments (e.g. Lindgaard & Henriksen 2011, Gubbay et al. 2016) were not included in the catalogue as there were insufficient data to produce maps of their distributions despite their known occurrence in different (or all) sub-regions of the respective sea basins.

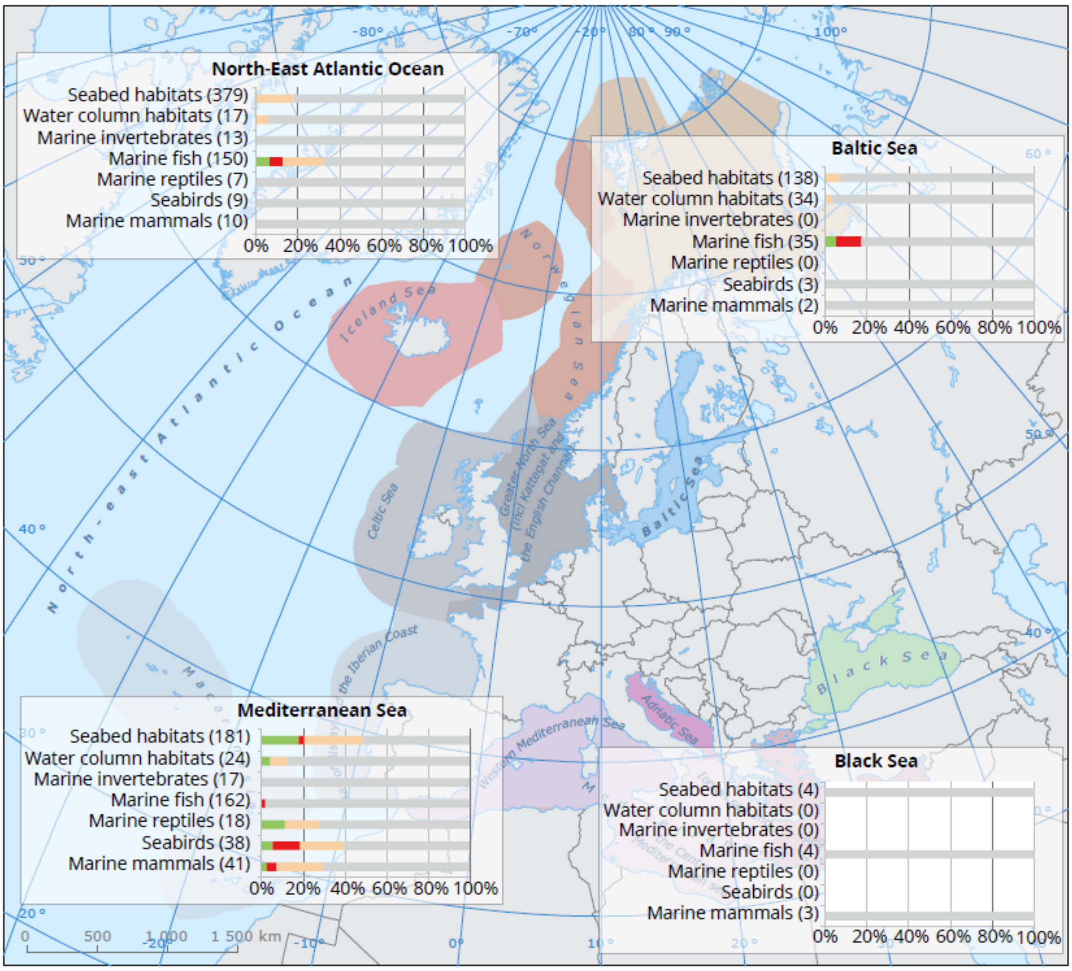
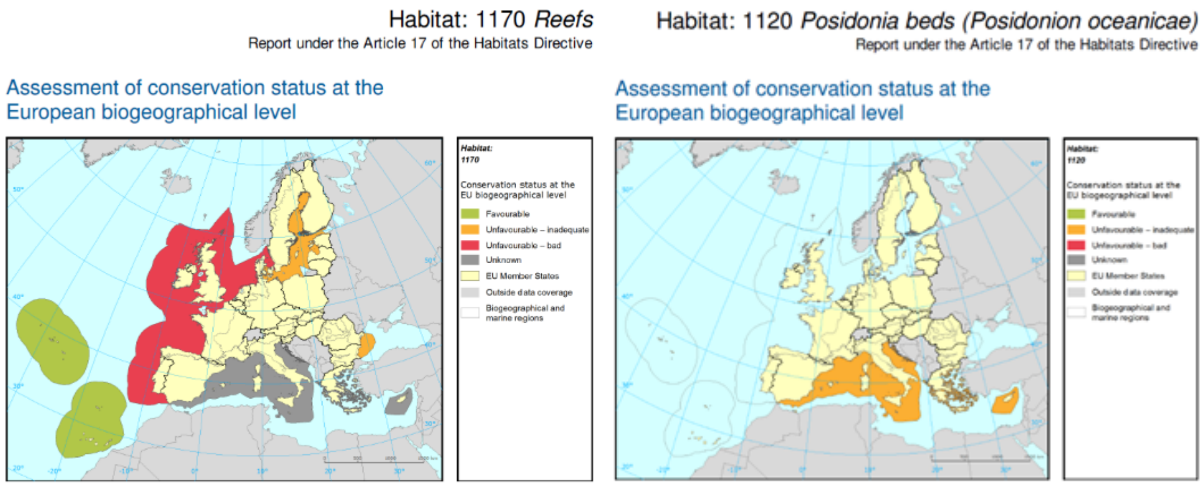


Figure 4.3. Status assessment of natural features, including seabed habitats in the European sea basins, reported by EU Member States under the MSFD (from EEA 2015). Different colours represent ecological status (Green: Good, Red: Not Good, Pink: Other, Grey: Unknown).

The MERCES Degraded habitats catalogue summarises available map resources on degraded habitats and so it does not provide a complete picture of worst cases with regard to the extent or level of degradation, unless this information was part of the examined maps. The geographic distribution of degraded habitat entries is similar to those presented above for the existing habitats (Section 4.1.2), concerning the geographic coverage of entries, specifically, indicating (a) a higher availability resources as a result of research effort (and funding) in the Mediterranean Sea and North-East Atlantic Ocean, or possibly (b) due to the increased activities and on-going pressures – and their effects to marine habitats – in the coastal zones in the above areas, and/or (c) a higher vulnerability of specific habitat types within these regions.

Entries for coastal sublittoral soft and hard substrate habitats dominated the catalogue with fewer entries for degraded deep-sea habitats. Most of the maps are for the North-East Atlantic Ocean (Celtic Seas, Bay of Biscay and the Iberian Coast) while there is an eastward declining trend within the Mediterranean, probably reflecting knowledge/research effort and funding. A high percentage of the entries include Priority and Protected Species/Habitats and/or Sensitive habitats/VMEs, mostly in the Mediterranean and the North-East Atlantic. Low percentage included Marine Protected Areas (MPAs) in agreement with recent relevant reviews (Gabrié et al. 2012)

In contrast to the habitats catalogue, most entries of degraded habitats are from peer-review papers; probably relating to the very high percentage providing only map images (published image in the paper) – accessible shapefiles are only available from on-line sources. Habitat inventories are often unable to report the extent of degradation, due to data gaps or the differences in the habitat classification systems, mapping and monitoring methodologies and threshold levels, adopted by different countries and/or international organizations. Specifically, in half of the entries, the assessment of degraded marine habitats is simply based on experimental/scientific observations while degraded habitats formally assessed in an Unfavourable/Sub-GES status are lower in number (Figure 4.4). Modelled or predicted status of degradation was derived from publications that use cumulative impact scores and indices at a basin or global geographical scale (Figure 4.5) (e.g. Halpern et al. 2008, Korpinen et al. 2012, 2013, Micheli et al. 2013, Katsanevakis et al. 2016), which may not accurately represent the actual level of degradation on the small scale.



Region	Conservation status (CS) of parameters: Range	Area	Structure & Functions	Future prospects	Current CS	Trend in CS	% in region	Previous CS	Reason for change
MATL	XX	XX	U2	U2	U2	-	65	XX	Genuine
MBAL	FV	FV	U1	U1	U1	-	21	U2	Not genuine
MBLS	XX	XX	U1	XX	U1	-	0.47	XX	Not genuine
MMAC	FV	FV	XX	FV	FV		6	FV	
MMED	FV	FV	XX	XX	XX	=	8	U1	Not genuine

Region	Conservation status (CS) of parameters: Range	Area	Structure & Functions	Future prospects	Current CS	Trend in CS	% in region	Previous CS	Reason for change
MMED	FV	U1	XX	XX	U1	=	100	U1	

Figure 4.4. Report under Article 17 of the Habitats Directive (2007-2012) for Reefs (left) and *Posidonia* beds (right) (bd.eionet.europa.eu/article17/reports2012/). Different colours represent different conservation status (Green: Favourable, Orange: Unfavourable - inadequate; Red: Unfavourable - bad; Grey: Unknown).

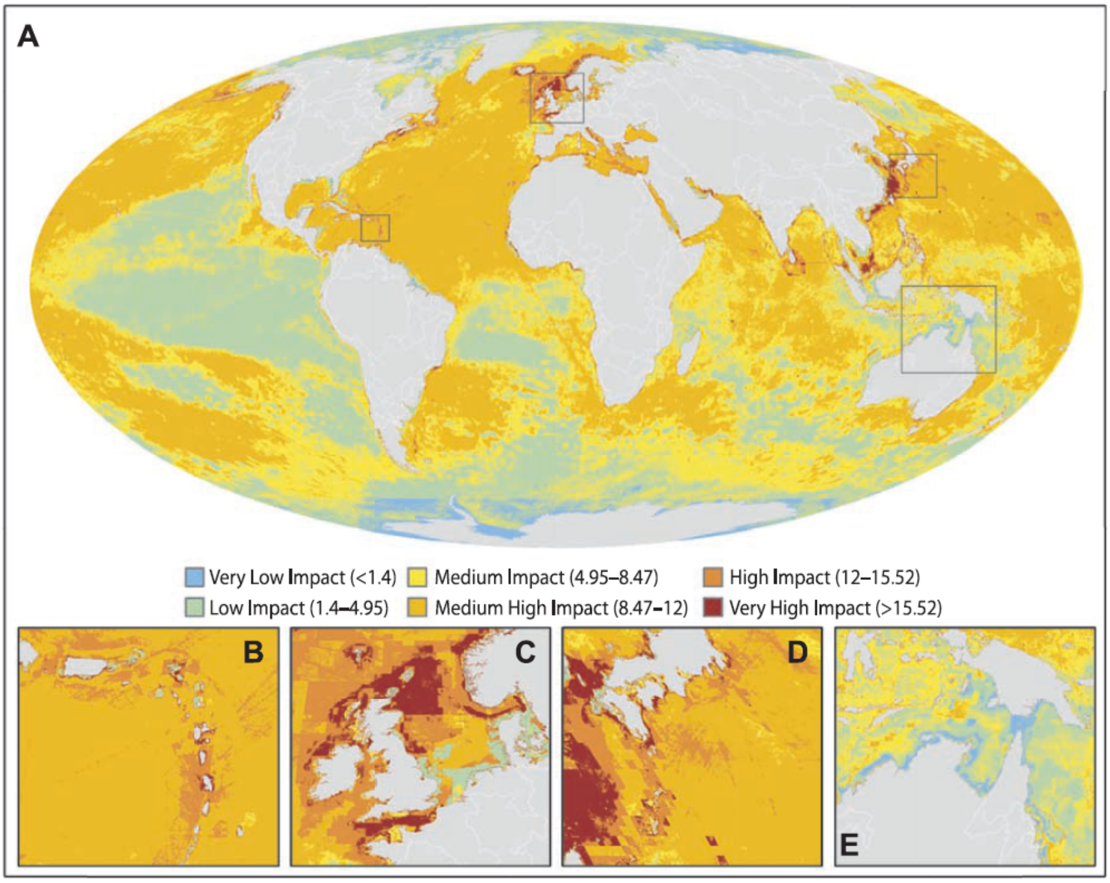


Figure 4.5. Global map of cumulative human impact across 20 ocean ecosystem types (e.g. seagrass, seamounts, rocky reefs, soft shallow, hard shelf, soft shelf, hard slope, soft slope, hard deep, soft deep) (from Halpern et al. 2008).

The analysis showed that information on the extent of decline of degraded habitats is of descriptive/qualitative nature or is absent in most catalogue map entries while there are very few sources relating to the recovery/restoration potential of the examined habitats (where they are present they tend to be based on expert opinion). According to these sources, the recovery/restoration potential of degraded habitats depends highly on the existing activities and pressures and the biological characteristics of the habitat's key species (e.g. growth rate). Active restoration as a sole activity is suggested in very few cases and tends to be in combination with mitigation, probably due to (a) the logistic constraints and cost for applying active restoration at large scales (e.g. regional level), or (b) the lack of mapping initiatives focusing on restoration activities. Mitigation and/or removal of activities causing habitat degradation and their impact (e.g. restrictions to fishing activities and MPAs), was the most frequently recommended practice, although it has been questioned whether mitigation should be considered as a form of restoration (see discussion in Elliot et al. 2007).

In all regions and major habitat types concerned, the majority of entries reported multiple activities and pressures (mostly physical and chemical), suggesting that mitigation measures are necessary (see

MERCES D1.2 report, Smith et al. 2017). The assignment of the reported activities and pressures to the various types of degraded marine habitats could form a first step towards identifying and linking specific activities and pressures with degradation. Such an attempt would be useful for managing and mitigating specific activities and pressures for the protection – and restoration – of different marine habitats and specific ecological features (e.g. see example in Box 1).

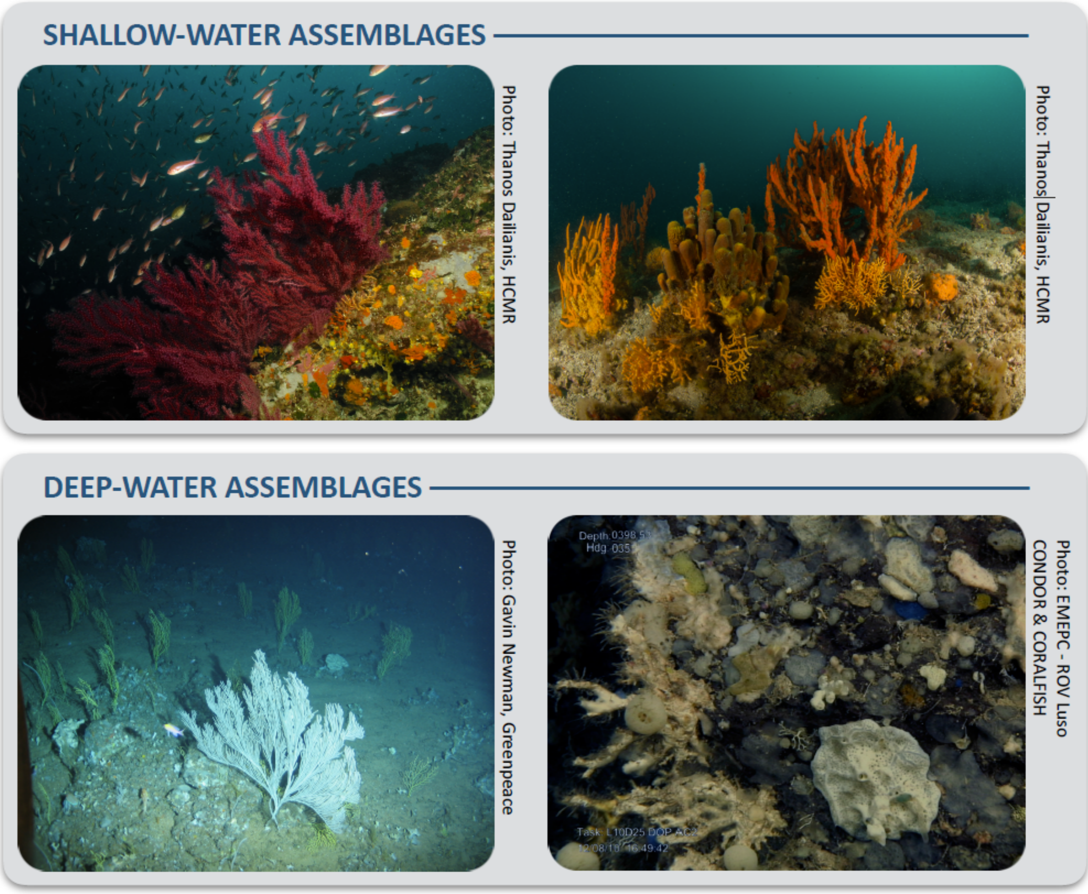
4.1.3 Gaps in the map resources

The systematic review regarding map resources for existing habitats and degraded habitats in the European seas revealed several limitations and gaps, with regard to the thematic, temporal and geographic coverage of the available map resources, as well as the resolution, availability and data format of the map resources. Consequently, it is recommended that future mapping initiatives should focus on the following:

- Production of high resolution and fine scale habitat maps;
- Ground-truthing of habitat maps, especially in cases of habitat modelling;
- Filling thematic gaps concerning specific habitats (e.g. deep-sea habitats and unmapped threatened/protected habitats);
- Filling geographical gaps regarding specific regions (sub-regions), supporting regional and national mapping initiatives;
- Filling temporal gaps through the digitization of old/historical maps;
- Increasing access to grey literature (e.g. online repositories);
- Promoting the publication of georeferenced data and GIS shapefiles (e.g. as supplementary files in papers or in online repositories).

Box 1. Degraded marine habitats and their restoration potential: an exercise focusing on sponge and anthozoan assemblages, using the MERCES catalogues

During the last decades, several European sponge and anthozoan species have been protected according to EU and international legislation (e.g. Bern and Barcelona conventions), and their assemblages are widely acknowledged as of great conservation concern (e.g. Gubbay et al. 2016). In the MERCES Habitats and Degraded habitats catalogues, 148 entries concern map sources on habitats hosting sponge and anthozoan assemblages, of which 54 report degraded habitats impacted by human activities, and endogenous (i.e. manageable within a local system) and exogenous (i.e. unmanageable with local measures) pressures. Most of these entries are from the Mediterranean Sea (53%) and the North-Eastern Atlantic Ocean (34%). Deep-sea habitats and features (e.g. cold-water coral and sponge assemblages, seamounts and canyons) and sublittoral hard substrate assemblages (e.g. gorgonian forests, coralligenous beds and sponge assemblages) dominate (44% and 43% entries, respectively).



Information on the decline of the habitats and features is mostly of descriptive/qualitative nature (46%) while in only 28% of the entries there is numerical/quantitative information and there is no information in 26% of the records. Knowledge on their recovery/restoration potential is lacking (52% of the entries) but there is a general concern that impacted coral colonies are unlikely to recover (28% of the entries) due to their slow growth rate, coupled with the increasing degree of human-induced impacts. Only 22% of the entries report an opinion-based positive recovery potential.

However, most of the examined sources (52% records) did not include any type of information about the recovery/restoration potential of these assemblages while 26% of the records reported a low recovery potential. Mitigation or removal of activities/impacts was the most frequently suggested restoration action.

4.2. The features of each case study habitat concerning restoration

The link between a pressure and habitat is inferred from the features (properties/characteristics) that influence and the habitat's degree of resistance, with groups of habitats that have similar features or properties assumed to respond in a similar way to the same pressure. For example, large, long-lived and fragile species and habitats (such as maerl beds, cold water corals) are particularly sensitive to pressures that cause physical damage (abrasion, subsurface penetration and disturbance), whilst sedimentary habitats are likely to have low resistance to substratum extraction resulting from fishing practices that lead to deep disturbance or dredging to remove aggregates or dredge channels. The following chapters will discuss the features of the different case habitats in relation to the chances for a successful restoration.

4.2.1 Seagrass meadows (shallow soft)

Many seagrass restoration techniques have been attempted with different species all over the world (e.g. Paling et al. 2009, Eriander et al. 2016). However, the overall success of seagrass restoration efforts has been quite low (37%, van Katwijk et al. 2009, 2016), which may be a consequence of not properly considering the features of the seagrass ecosystem in question. Seagrass meadows are highly susceptible to environmental changes, and are regulated by a variety of interspecific interactions such as competition with filamentous algae (Gustafsson & Boström 2014), herbivores grazing directly on seagrasses (Preen 1995, Christianen et al. 2014), herbivores grazing on epiphytes (Gacia et al. 1999), and bioturbation by infaunal organisms (Castorani et al. 2014). Furthermore, positive and negative feedbacks also play an essential role in seagrass ecosystems, and these interactions and feedbacks must be considered during restoration (van der Heide et al. 2007, 2011, Maxwell et al. 2016, Suykerbuyk et al. 2016). Successful restoration of seagrass ecosystems likely depends on a number of traits and characteristics that must be carefully considered prior to attempting restoration and at all stages throughout the restoration process (Figure 4.6, Węsławski et al. 2017). Important traits include those related to the seagrass species in question such as the growth rate and mode of reproduction (i.e. slow-growing species will require longer restoration time scales than fast-growing species) as well as the traits of the donor population (genetic diversity, plant species diversity, spatial distribution, depth, and tidal height).

Another important thing to consider is the recipient site. An ideal recipient site should have high restoration potential, including similar physical (sediment type, depth, temperature, exposure, salinity, and nutrients) and biological (presence of grazers feeding on eelgrass or preventing algal blooms, bioturbators, facilitating species) characteristics as the donor site or at least appropriate for the for the seagrass species being restored (Peralta et al. 2003, van Katwjik & Wijgergangs 2004, Di Maida et al. 2013). Proximity to natural seagrass meadows may also increase restoration potential as it ensures connectivity (spread of seeds) between populations and thus increased genotypic diversity. Most importantly, given the vulnerability of seagrasses, steps must be taken to ensure that anthropogenic stressors such as nutrient enrichment and pollution should be reduced before restoration and protection measures put into place if necessary to prevent disturbances (Burkholder et al. 2007, Park et al. 2009, García et al. 2013). Without such measures, restoration potential is low and unlikely to succeed. Finally, selecting the appropriate methodology for transplantation will depend on the site characteristics, but key among these are to restore over large enough spatial scales which will allow for positive feedback mechanisms to occur, and to conserve genetic and/or species diversity (Gustafsson & Boström 2011, Reynolds et al. 2012, Jahnke et al. 2015).

Finally, success criteria and goals should be established, which should take into account the features of the seagrass species in question. For example, restoration success of a slow-growing species such as *Posidonia oceanica* cannot be assessed on the same spatial scale as fast-growing *Zostera marina*. Restoration success should also take into account eelgrass-associated species; restored seagrasses should attract other species and be self-sustaining in the long-term through positive feedbacks and interactions. In addition, climate change, natural disturbances, and disease outbreaks can have negative impacts on seagrass species and these must be taken into consideration and managed during the restoration process (e.g. Preen et al. 1995, Björk et al. 2008, Sullivan et al. 2013, Olsen & Duarte 2015, Unsworth et al. 2015, Thomson et al. 2015, Govers et al. 2016).

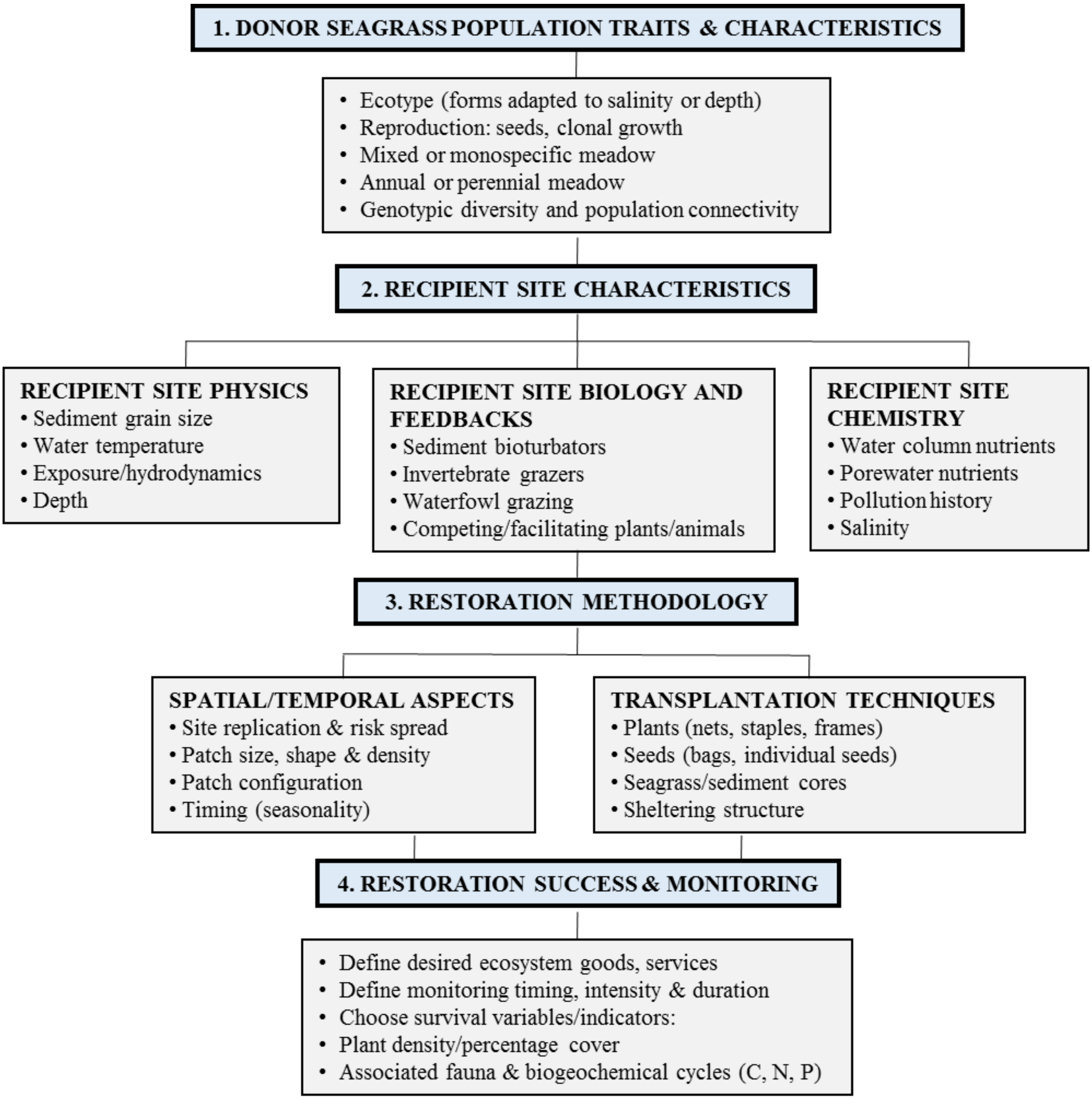


Figure 4.6. Outline of a seagrass restoration plan and the factors which must be taken into account at each stage of the plan (from Weslawksi et al. 2017). The numbers 1-4 relates to the features described and discussed in Table 3.2.

4.2.2 Macroalgae/kelp beds and forests (shallow hard)

Kelp forests have been grazed down by sea urchins in temperate coastlines globally (Filbee-Dexter & Scheibling 2014), which has resulted in large-scale shifts from highly productive, pristine kelp forests to desert-like barren grounds. Many species of sea urchins inhabit kelp forests of the north Atlantic in low densities (Skadsheim et al. 1995, Steneck et al. 2004, Sjøtun et al. 2006). During blooms, the density may exceed 100 individuals per m^2 (Lang & Mann 1976, Hjörleifsson et al. 1995, Sivertsen 1997a) and these aggregations may create fronts grazing down the kelp forests. This may result in a regime shift, resulting in a new stable state (Scheffer et al. 2001) of barren grounds in which sea urchins dominate for decades (Elner & Vadas 1990, Keats 1991, Sivertsen 1997b, Steneck et al. 2004, Norderhaug & Christie 2009). Few attempts have been made to switch these barrens back to the kelp forest state. However, some attempts have been made to use artificial reefs to promote recovery of *Laminaria hyperborea* kelp forest at barrens in the Barents Sea in northern Norway, with time-limited success (unpublished NIVA data). The reefs were successfully colonized by sugar kelp soon after deployment of the reefs, and created lush kelp forests for at least for 2 years. However, when revisited years later, the sea urchins were able to graze the reefs. Experiences from the use of artificial reefs in Japan shows that an ecosystem with predators are needed for long-term effects (Fujita 2011). This is also implied by the recent knowledge of the importance of crabs as predators on sea urchins, facilitating the recovery of kelp in Norway (unpublished NIVA data) as well as in Main (Steneck et al. 2013). The use of artificial reefs is a well-established method to compensate and replace lost habitats due to e.g. urbanisation. Kelp restoration studies using quicklime have been shown to be an efficient method for reducing sea urchin abundance over relatively large spatial scale (Bernstein & Welsford 1982). As with the use of artificial reefs, the lime treatment by itself is not sufficient to ensure long-term restoration. Hence, in a new project (most likely starting June 2017) NIVA and the Institute of Marine Research (IMR) will test the combined use of artificial reefs and burnt lime as a restoration measure in barren areas in northern Norway. Adding predatory fish or crabs could be a needed supplement to ensure long-term success. A community with a high biodiversity will have a higher robustness against sea urchin grazing (Bernhardt & Leslie 2013) and will normally house a sufficient amount and diversity of predators to control the sea urchins (Steneck et al. 2013). Hence, the chances for successful long-term restoration of kelp are likely to increase with increase in recovered biodiversity. To ensure kelp recovery, it is, as stated earlier, important that the restoration sites have suitable conditions for kelp growth and survival, including optimal light (not too deep locations) and wave exposure conditions (not too sheltered). It would also be wise to choose restoration areas that are known to have e.g. crab predators, that can be able to control the sea urchin populations. Areas in progress of natural recovery, but where small changes in sea urchin densities can flip the recovery back to barren state, should have high priority for restoration actions.

When it comes to Cystoseira forests, carrying out a restoration action is necessary to reverse or mitigate the impact. However, species of *Cystoseira* grow in many different type of habitats, with different ecological requirements. To properly select the transplantation habitats, the appropriate donor population, and the optimal transplantation technique will ultimately determine the restoration success. In addition, the restoration success evaluation will also require long term monitoring (specially for long-live species) to evaluate some attributes than can be complex and involve long-term processes. It is the case of some functional traits, such as the first age/size of sexual maturity of the restored population individuals to ensure the self-maintaining population (which for some species can be after 3 or 4 years. However, whether or not restored population provides all services to the habitat, and therefore habitat restoration has been successfully reached, is difficult to assess. Some ecological indicators, such as population size-structure or habitat biodiversity, are the most reliable candidate to assess the restoration success. According to the available literature, the critical state of conservation and the low recruitment of many *Cystoseira* populations the advice for restoration methods is to enhance recruitment without manipulating juveniles or adults from existing populations, which are in many cases already under multiple pressures. Many *Cystoseira* populations have specific ecological requirements, so that successful restoration actions have to be planned in areas where the existence of *Cystoseira* was already recorded and thus ecological conditions will completely fit with *Cystoseira* needs, once potential disturbances will be completely removed. Finally, the restoration actions should take into account the specific population dynamics for each species, which in some cases can be relatively slow, leading to long time for a complete recovery.

The low resilience of *Cystoseira* often prevent the recovery even after decades of low disturbance. The low dispersion of *Cystoseira* zygotes that limits new individuals to the proximity of parents could also contribute to limiting the recovery of disturbed *Cystoseira* populations. Actually, some studies deal with the influence of temperature, light intensity, sedimentation on the survival and growth of recent settled germlings of *C. barbata.* In parallel, natural recovery of algae forests involving forests impacted by overgrazing are limited by a hysteresis effect of approximately one order of magnitude in grazer biomass between critical thresholds of overgrazing and recovery. Therefore, many restoration actions of overgrazed populations will need of a continuous control of the grazing activity, besides increasing recruitment enhancement or adult density from donor populations. In this framework, there are available examples of restoration methods that include, both in the intertidal and in the subtidal, the exclusion or limitation of herbivores, as well as cages, nets or manual removal, as well as restoration methods that include the ex-situ culture of recruits in the laboratory and consequently avoiding all these first life stage impacts.

4.2.3 Coralligenous assemblages (shallow hard)

To date, efforts on restoration of coralligenous outcrops, a structurally complex habitat endemic to the Mediterranean Sea, were focused on the transplantation of fragments of several habitat-forming species, namely few gorgonians and a single sponge species (Linares et al. 2008a, Fava et al. 2010, Montero-Serra et al. 2017). Such an approach is bypassing sensitive early life stages (e.g. Linares at al. 2008a,b) and these studies confirm the feasibility of the method on the local spatial scale. However, bearing in mind that most of structurally important coralligenous species (including the ones used in the transplantation experiments so far) are slow-growing, long-lived organisms (Ballesteros 2006, Teixidó et al. 2011), expected dynamics of recovery is low and thus, timescales at which a restored coralligenous habitat i.e. the one with recovered structural complexity that can provide ecosystem services at rates similar to natural ones, are long. As an illustration, a recent study based on the transplantation experiment and demographic modelling methods predicted 30-40 years for a recovery of the fully functional population of the habitat-forming red coral *Corallium rubrum* (Montero-Serra et al. 2017), a typical species representative of the dynamics of the coralligenous assemblages. Thus, it cannot be expected that a short-term monitoring (e.g. during general life-time of the individual projects, including MERCES) will reveal a fully recovered populations and habitat but tangible restoration success may be still reached even over short term, as observed in the case of the red coral transplantation in the Medes Islands MPA, resulting in the high survival of the transplants and their reproductive potential comparable to the natural populations (Montero-Serra et al. 2017).

Restoration projects on hard sublittoral bottoms are quite well developed in tropical areas (Horoszowski-Fridman & Rinkevich 2017) but very little information is available for temperate seas, including the Mediterranean Sea. It makes sense to focus restoration action in areas where the causes of degradation are no longer present. Currently, the most important threats for restoration action in the Mediterranean Sea in sublittoral habitats are the thermal anomalies (Garrabou et al. 2009, Cerrano & Bavestrello 2008, Huete-Stauffer et al. 2011, Di Camillo & Cerrano 2015). Even if there is the possibility that some species, generation after generation, can slowly adapt to the increase of the average sea-water temperatures (e.g. *Corallium rubrum*, Torrents et al. 2008), this not the rule. Consequently, restoration should be addressed below the thermocline.

Another threat that could negatively affect the success of a restoration project on hard bottom communities is mucilage outbreaks (Giulani et al. 2005). These events are becoming more frequent in the Western Mediterranean Sea and can heavily compromise the reproductive output and the recruitment phase of many species. Mucilage wraps benthic organisms, especially those with an upright growth form. They can suffocate smaller colonies and, in the context of restoration activities, transplants can be compared to young colonies (Fava et al. 2010).

It is a challenge that the assessment of coralligenous restoration success requires long-term monitoring – often the value of such efforts is not recognized and the continuous funding is not easily secured. For many structurally and functionally important coralligenous species the basic biological knowledge, that could support the most sound and cost-effective restoration efforts, is still lacking, e.g. the knowledge on life cycles, reproductive biology (including age/size at the first reproduction), connectivity, recruitment and growth rates, life span and population structure. Potentially,

- Transplantation may be a suitable restoration method for many of the structurally important coralligenous species
- Survival rates of transplanted slow-growing coralligenous species may be high and therefore,

lower initial restoration effort is needed (e.g. Montero-Serra et al. 2017)

- Improved understanding of the engineering-mediated species interactions and facilitation mechanisms could offer a promising venue for coralligenous restoration
- long-term studies can be partially substituted by modelling approaches; however ongoing longer term restoration and monitoring efforts should be further supported in order to gain valuable knowledge on these low-dynamics systems, accessible only from direct observations through time

4.2.4 Deep sea coral gardens

MERCES will suggest and develop tools and methodologies for restoration practices, including for deep-sea ecosystems. Increased human pressures in the deep-sea have impacted some ecosystems (e.g. cold-water coral reefs and gardens, sponge aggregations) beyond the point that the ecosystem can recover without direct human intervention, at least in our lifetime scale, emphasising the need to include restoration actions for the sustainable management of these ecosystems (Van Dover et al. 2014, Barbier et al. 2014). Desktop deep-sea restoration scenarios have demonstrated that, in general, the principles and attributes of ecological restoration, originally formulated for terrestrial and coastal ecosystems, can be applied to the deep sea (Van Dover et al. 2014). Therefore, within MERCES, the objective is to build upon the methodologies developed for shallow water marine ecosystems to develop practices for deep-sea restoration in different deep-sea ecosystems and at geographical scales relevant to management using pilot studies. One such pilot study aims to develop the active restoration, also called assisted regeneration of degraded coral gardens habitats. Coral gardens share many of the ecological attributes described for coralligenous habitats, namely being composed of slow-growing, long-lived organisms (e.g. gorgonians, black corals, Watling et al. 2011, Carreiro-Silva et al. 2013), lack of knowledge on the basic biology of these organisms (reproductive and larval biology) and population connectivity. Therefore, some of the challenges identified for coralligenous habitats and proposed solutions are very similar. In this sense, active restoration actions should focus on techniques using adult coral colonies instead of early life stages (e.g. producing larvae in aquaria for seeding restoration areas). The proposed method is the transplantation of fragments of adult colonies similar to what has been done for red gorgonian populations in the Mediterranean (e.g. Linares et al. 2008a, Fava et al. 2010, Montero-Serra et al. 2017). In the Azores, complex arborescent coral colonies are frequently accidentally captured during commercial fishing operations. Researchers are therefore working together with fisherman and fisheries observers to recover these corals and test the feasibility of replanting them back at sea. This strategy minimizes the impact on natural potential donor coral populations, and overcomes the need for expensive technology, reducing the overall cost of the restoration action. Other reasons for the use of adult colonies include the immediate recovery of the three-dimensional structure, facilitating the recovery of habitat-forming functions as structural habitat for associated species. By using coral bycatch material, we are also likely increasing the genetic diversity of the parent donor coral colonies used for restoration. This is because fishing operations cover a much wider spatial scale that could be used with technological means (e.g. ROV).

There are a number factors that should be considered to guarantee the success of the transplantation restoration actions: (1) the species of choice for the restoration action should have relatively fast growth rates, in this sense, gorgonian corals should be given priority over black corals; (2) given the lack of information on larvae biology and connectivity patterns, the restoration site should be in the proximity to natural coral garden habitats to ensure connectivity between populations; (3) given the high costs associated with restoring large spatial areas, an option to be considered would be to have several small local restoration sites with transplanted corals that would be connected by oceanographic patterns (currents) and would ensure natural seeding of the coral populations. In addition, considering that coral larvae need hard substrate where to settle, the use of settlement plates together with transplantation techniques may contribute to extend the spatial area covered by the coral garden habitat.

Two additional important aspects to consider are related to the management actions that need to be placed in concert with the restoration activity. Corals are highly vulnerable to human pressures. Therefore, any restoration actions should act in concert with protection measures that remove as much pressures as possible from the area to be restored (e.g. closure to fishing activities), until a certain threshold of size/biomass of coral colonies or area covered by coral colonies is attained. Moreover, because of the patchy or fragmented nature of deep-sea coral gardens, a combination of restoration approaches will likely be necessary, with natural regeneration (through fisheries closures, marine protected areas) at large scales and natural regeneration and reconstruction at smaller scales. Finally, as in the case of coralligenous habitats, and given the life history traits of corals, short-term monitoring (i.e. within the lifetime of the MERCES project) cannot be expected to reveal fully restored habitats. Therefore, management measures should be taken to ensure the long-term monitoring of the restored area, well beyond the end of the MERCES project.

Ecological restoration of the deep-sea ecosystem in general and coral gardens in particular may be a challenging task. In some cases, describing reference coral garden ecosystems representing sites where degradation has not occurred may be difficult, as bottom fishing may have had significant impacts in most of the existing sites. Even if a reference ecosystem is well described in terms of compositional, structural and functional attributes, restoring the full range of attributes may be difficult. This because individual native species will regenerate naturally at different time scales, and because assisted regeneration or reconstruction may be feasible only for a limited number of species. It is also because of the extremely long term nature of recovery processes, limiting the capacity for achieving full recovery. Nevertheless, appropriated ecological restoration approaches for coral gardens should consider the combination of the three restoration approaches (natural regeneration, assisted regeneration and reconstruction) and the definition of achievable goals and objectives.

4.2.5 Deep-sea communities

Restoration strategies should be promoted for deep-sea habitats degraded by mining operations, oil spills, bottom trawling or other sources of impact. Plans are currently underway to start experiments for restoration of hydrothermal vents, cold seeps (with mineral crusts) and manganese nodules after mining (Coffey Natural System 2008, Van Dover et al. 2014, International Seabed Authority 2016). Efforts are also ongoing to develop swarms of autonomous underwater vehicles to support deep-sea restoration efforts over broad geographical areas (Rogers et al. 2015).

A key issue regarding deep-sea restoration focuses on the obligation of responsible parties (e.g. mining and fishing industries) to undertake steps to repair damage that result from commercial or other activities that affect marine ecosystems (Coffey Natural Systems 2008, Van Dover et al. 2014). In recognition of the high impact of trawl fishing in the deep seas and the Vulnerable Marine Ecosystems (VMEs), EU has recently (2016) reached a landmark agreement to implement new regulations to stop trawl fishing in depths over 800 meters in the NE Atlantic. A similar ban to trawl fishing below 1000 m depth exists in the Mediterranean. However, high seas bottom fisheries have not yet taken the responsibility for restoring sea-bed ecosystems after impacts of trawling activities. On the contrary, the voluntary IMMS Code for Environmental Management of Marine Mining developed by the International Marine Minerals Society (Verlaan 2011, International Seabed Authority 2016) recommended that plans for mining must include procedures that "aid the recruitment, re-establishment and migration of biota and assist in the study of undisturbed, comparable habitats before, during, and after mining operation". Verlaan (2011) underscored the importance of "long-term monitoring at suitable spatial and temporal scales and definition of the period necessary to ensure remediation plans are effective". Recently an international team of experts suggested the priority of a new international agreement for a global deep-ocean monitoring strategy to expand our capacity to protect and restore deep-sea ecosystems and their resources (Danovaro et al. 2017). Such plans have been already incorporated into the Environmental Impact Statement of the first project to propose mineral extraction at a deep-sea site (Coffey Natural Systems 2008).

Challenges - Restoration of deep-sea ecosystems challenging, as the pre-disturbance baselines are generally unknown, making it difficult to assess the impact of anthropogenic activities on benthic groups and identify the best practical solutions. For each type of degraded ecosystem, pre-disturbance baseline studies should be undertaken as part of the Environmental Impact Assessment process. Another important issue is to define criteria to use for selecting areas for ecological restoration to optimize cost-benefits and the ecological impact since deep-sea ecosystems host a high diversity (at taxonomic, functional and genetic level) and endemism (Grassle & Maciolek 1992). Moreover, some indigenous taxa present low abundance in deep-sea sediments and their rarity could represent an additional issue for the success of the restoration practices. Due to the high diversity of deep-sea habitats and their spatial distribution and extension (Danovaro et al. 2014), the key challenge to promote deep-sea restoration is to clarify and prioritize its opportunities and the possible recovery in terms of good and ecosystem services. The basic decision parameters that determine whether or not to restore fall into at least three broad categories of decision parameters: socio-economic, ecological, and technological factors. Exploring and documenting deep-sea ecosystems is very expensive, therefore the costs of restoration are higher (likely orders of magnitude) than those reported on terrestrial or coastal ecosystems, due to the remote and technically challenging aspects of deep-sea manipulations (Danovaro et al. 2014, Van Dover et al. 2014). Where active restoration is prohibitively expensive or technically unfeasible, other actions (i.e. unassisted restoration) should be considered as a valid alternative tool (Van Dover et al. 2014). Since deep-sea restoration is expensive and represents a long-term investment undertaken in the context of societal priorities, this requires many resources (i.e. funds, time) from a diverse portfolio of investors and participants. Multi-stakeholder engagement could be effective means to share costs, maximize benefits of restoration actions and make collective decisions about whether or not restoration at a particular site is a viable option (Wedding et al. 2015). The ecological restoration in the deep sea is still a challenge, in particular to understand how pilot initiatives at small scale can be translated to those at large spatial scale.

Gaps – The deep sea hosts a huge biodiversity, but the spatial and temporal scale of ecological and genetic connectivity is poorly known. Species connectivity is an important issue for all benthic groups but it is scantly investigated in deep-sea ecosystems due to the limit of the sampling efforts. The lack of information about connectivity of deep-sea soft bottom communities can be considered an issue for the effectiveness of the restoration initiatives. Deep-sea species are often endemic to a specific system, thus their spatial distribution is difficulty assessed and consequences of restoration practices are unknown for biodiversity, species composition and functional groups. The advances in the ecological restoration science and technology, from genes to whole landscapes, have to be considered as a priority to improve the sustainability and effectiveness of the restoration practices in deep-sea ecosystems (Van Dover et al. 2014). Such efforts will improve the ability to identify worthwhile restoration activities to protect deep-sea biodiversity and ecosystem functioning, in order to guarantee the delivery of services important for human well-being.

Potential - Principles and attributes of ecological restoration, originally formulated for terrestrial and coastal ecosystems can be applied to the deep sea. Different growth rates (slow/fast) of different trophic groups (i.e. microbes, meio-, macro- and megafauna) influence the survival rates after a disturbance and their potential recovery after the end of disturbances. We can also expect that the recovery of soft bottom communities after the end of disturbances can be different in different investigated habitats (open slopes, seamounts, canyons and deep basins) and regions since the response of benthic components is driven by environmental and trophic conditions (Witte et al. 2003, Danovaro et al. 2008a,b, De Leo et al. 2014). The removal of impacts is a priority to allow a recovery of benthic groups and the conservation of habitats can be considered a valid tool that can support restoration initiatives and guarantee the protection of the restored areas against new impacts/disturbances (Van Dover et al. 2014).

4.3. Summing up the lessons learned

Technologies and methods that reduce costs and increase success rates are increasingly available, and the restoration sector is gradually gathering expertise. However, joint efforts, shared protocols and broad-scale tests of different methods are required in order to make restoration practices effective (Seaman 2007). Although the restoration of degraded ecosystems can be an expensive and lengthy process, "working with nature" may provide cost-effective solutions (SER 2004), which implies knowing about any natural conditions or relationships that make restoration a success. The degree to which a particular habitat is vulnerable to a specific pressure is a function of its resilience (consisting of resistance and recovery potential) and its exposure to the pressure. The basic principles and attributes of ecological restoration, originally formulated for terrestrial ecosystems, can also be applied to the marine systems (Mengerink et al. 2014, Van Dover et al. 2014). For example, identifying the need for restoration, mitigating anthropogenic pressures, considering processes and feedbacks (Maxwell et al. 2016), and setting appropriate goals and metrics for determining success are necessary steps in restoring any ecosystem, whether terrestrial or marine (Baggett et al. 2015).

It has been demonstrated that optimal conservation outcomes can be achieved through the restoration of degraded habitats (Possingham et al. 2015). However, the reliability and efficiency of restoration actions carried out across different marine ecosystems in European seas varies. Even though successful restoration attempts have been made over the world in the last decades, restorative projects in the marine environment remain expensive and therefore mainly occur on small, local spatial scales over a short time scale (1-2 years), with varying degrees of success (Bayraktarov et al. 2016, Montero-Serra et al. 2017). The success rate of marine restoration projects can be quite low (van Katwijk et al. 2016) and depending on habitat. Recent reviews indicated that salt marshes and tropical coral reefs have relatively high success rates, both 65%, while seagrass restoration projects succeed only 37-38% of the time (Bayraktarov et al. 2016, van Katwijk et al. 2016).

There is a need to better understand the interactions that exist between ecosystem features and cumulative pressures to deliver more efficient restorative actions. In order to facilitate this process, MERCES, using a multidisciplinary and integrated approach, is seeking to create new tools, and evaluate existing ones, that can be used to restore ecosystem functioning and services delivered by European marine habitats. As a precursor to this ambition, this report details current levels of knowledge relating to the distribution of MERCES focal habitats, the degree to which degraded habitats have been mapped and issues of relevance to enhance restoration actions in view to promote the full recovery of habitats.

Considering ecological restoration should lead to the recovery of an ecosystem that has been affected by human activities, we therefore need good baselines to set suitable restoration goals and indicators and timing of success. The data collected in the catalogues developed in WP1 of MERCES showed an obvious lack of accessible geo-referenced information (e.g. shapefiles), which limits the possibility of extraction and further use of habitat inventory data. The general lack of historical knowledge on marine habitats results in several indirect approaches, such as historical ecology (e.g. analyses of old photos, McClenachan et al. 2012) and local ecological knowledge methodologies (Bastari et al. 2017).

A challenge for restoration is the lack of comprehensive knowledge on the link between a pressure and a change in ecological state or condition. This relationship is often assumed to be a linear process, i.e. as the pressure increases the condition of the habitat decreases (Kemp et al. 2009). However, the ecological literature provides numerous examples of ecosystem not returning to their historic baseline (Duarte et al 2009) due to shifting baselines (Conley et al. 2007) and nonlinear relationships between predictor and response variables (see Hunsicker et al. 2016 for an example on "tipping points"), including responses exhibited at individual, population, species, and ecosystem levels (Mee 2006, Wilson et al. 2008, Kemp et al. 2009). The concept of hysteresis has significant implications for ecosystem restoration because it describes the different pathways of degradation and subsequent recovery (Suding and Hobbs 2009). It is triggered by dynamic and interacting environmental stressors (e.g. eutrophication, overfishing, climate change, food web alterations) and eventually explains why some ecosystems may return unexpected responses to restoration despite reduced pressures.

A MERCES project challenge is to tackle all the features and consequences for restoration between different target habitats and species. It will shed light on habitats crucial for their value as species and functional diversity, the service they provide to the ecosystem and their fragility and vulnerability. However, those habitats mostly cover relatively small areas and are certainly not as dominant as, for example, the rest of the bottom habitats, which are mostly left quite unexplored. Our catalogue and analysis both show consistent patterns that we consider crucial to help the development of restoration protocols able to promote meaningful planning and success of restoration actions over coherent ecological frameworks implying larger spatial and temporal scales.

There is a consistent trade-off between survival and growth across species, displaying contrasting life history and functional traits, which in turn drives a trade-off between necessary initial transplantation efforts and the maximum possible speed of recovery (Montero-Serra et al. 2017). Regarding connectivity, habitat forming species, in general, are characterized by low connectivity while species showing high trophic interactions with macroalgal and seagrasses species (e.g. sea urchins, fishes and crustacean) display high population connectivity. Finally, focal habitats are mostly dominated by long-lived species, characterized by slow growth and low natural mortality rates, thereby showing apparent stability even though along a declining pathway (Hughes et al. 2013). These contrasted patterns have implications in the design of restoration actions. Restoration activities dealing directly with habitat forming species should be based on sets of local actions while activities focused on removal of biotic pressures should consider large scales to be effective. Because life history and functional traits are highly correlated, favouring specific strategies for structural species can have long-term consequences for habitat complexity and associated diversity.

Comparing the features of different cases study habitats (Tables 4.1) we scored our target habitats according to their potential for restoration, from the lowest to the highest: deep-sea coral garden and deep-sea bottom communities, coralligenous assemblages, seagrass meadows, and rocky coastal macroalgal forests.

Deep-sea coral gardens, together with deep-sea bottom communities, are, according to our scoring (Table 4.1), the most challenging to achieve acceptable restoration goals. This is partly due to coral life history traits such as extremely slow growth rates, long lifespans (thus likely late age of first maturity), low fecundity, and high vulnerability to human impacts of key indicator species, and due to the limited information on larvae biology and dispersal and population connectivity. In addition, a high number of factors need to be taken at same time into account to enhance the restorative action. For example, human pressures should be removed as much as possible, species with high survival and growth rates should be prioritized and restoration should cover large spatial areas (Table 3.8). The challenge of restoration of deep-sea bottom communities is due to the high levels of uncertainty associated with the life-history traits and population dynamics of targeted species. (Table 3.9). The remoteness of these communities makes restoration highly dependent on technological means (e.g. large ships, ROVs), which considerably increases the costs of the restoration actions in comparison with shallow water habitats (van Dover et al. 2014).

The restoration success in seagrass meadows is difficult to assess. While restoration success has been low so far, it is in fact likely be highly dependent 1) upon the species present, for example, *Zostera* grows quickly, but *Posidonia* is quite slow growing, and 2) on the location of the restoration activity, for example, in general, populations have high connectivity apart from in the Baltic Sea which is characterized by old, mega clones (i.e. genetically highly isolated meadows) (Table 3.2).

Coralligenous assemblages have extremely high diversity and complexity, which make restoration challenging. Though intervention may not be as logistically difficult as for deep-sea thanks to a shallower bathymetrical distribution, we scored its restoration potential very low because its slow growth rate, low connectivity, high vulnerability and fragility to human activities and its extreme structural complexity. We think that acting on human pressure, as reducing nutrient enrichment, sedimentation and physical damage from trawling, anchoring, or diving may reduce vulnerability and fragility a lot (Table 3.7). However, the clonal nature of most of targeted species should enhance restoration actions since donor colonies are abundant and damage to these colonies are limited. Preliminary field studies indicated good potential for restoration actions (Linares et al. 2008a, Fava et al. 2010, Montero-Serra et al. 2017). The transplants show great survivorship and restored populations achieve similar functional traits compared to natural populations in few years (e.g. reproduction output) (Montero-Serra et al. 2017). The main constrain for coralligenous is that demographic projections predict that several decades may be required for fully functional of habitat forming species populations to develop (e.g. Teixidó et al. 2011, Montero-Serra et al. 2017).

Hard macroalgal forests can be considered as "Medium" in terms of likelihood of success of the restoration activity, due to their medium connectivity and medium-high vulnerability (Table 3.5 and 3.6). Although many species are continuously discovered belonging to this habitat, it seems they all having a potential for a restoration success thanks to their common ecological properties. Shallow hard macroalgal forest might be relatively easier to restore in comparison to deeper macroalgal forest thanks to their higher growing rates. Apparently nutrient and light availability acts as limiting factors for deeper habitat, therefore slowing down its dynamics. This may be a key factor for a restoration success in deeper forest. Macroalgal species dwelling in coastal areas display an increase in lifespan and a reduction of population dynamics along depth (0 to 50 m depth, Capdevila et al. 2016). This differential dynamic should be taken into account along their restoration action.

Of the focal habitats selected, shallow hard kelp forest will probably be the habitats with highest likelihood of restoration success due to their fast growth rates, high levels of connectivity and low levels of vulnerability (Table 3.3 and 3.4). An example of successful restoration is the LIFE BlueReef project, restoring offshore cavernous boulder reefs (with macroalgae) in shallow waters in Kattegat, recovering a stable system when it comes to structure and function (naturstyrelsen.dk/naturbeskyttelse/naturprojekter/blue-reef/).

Rate of dynamics and connectivity are key habitat properties that make restoration more or less challenging. Although they are mostly due to ecological features of the composing species, environmental conditions may enhance such features. Environmental conditions could act as limiting factors (e.g. in case of low nutrients availability, lower dynamics were observed due to low growth rate). Furthermore, there is a negative relationship between habitat dynamics and vulnerability/fragility. High dynamics corresponds to low vulnerability/fragility. This suggests that acting on dynamics may improve fragility and vulnerability at same time.

In practice restoration is not that easy for any of the habitats studied and prevention of impacts, spatio-temporal regulation of activities and mitigation and compensation are among the first choices for management action. Reviewed case studies examples highlight the importance of human activity restrictions, pressure alleviation and mitigation options (Smith et al. 2017, D.1.2. MERCES Deliverable).

Beyond considering external exchanges, species composition, structural diversity, ecosystem function (McDonald et al 2016), key factors for a successful restoration are synergistic actions such as 1) careful choice of the restoration site, 2) implementation (or knowledge of existing) measures for the reduction of the source of degradation, 3) an appropriate handling of weak features, which induces 4) a reduction of habitat fragility.

When information is sufficient to document that a habitat is degraded it is possible to design restoration activities. We firstly need two basic tools: i) the best technique to manipulate different species to restore the ecological structure and function of targeted habitat and ii) the ability to evaluate whether the manipulation has triggered the desired effects. Once the proper set of protocols is fixed and restoration completed, the new assemblage begins to become established and ecosystem functioning should be added to the monitoring program. Usually the long-term performance of a restoration process is evaluated taking in account the physical complexity of the restored habitat. However, measurements of functional characteristics can offer a more precise picture on how the restored habitat is performing and if the expected economic and ecological services are achieved although these rarely appear among the criteria used to measure the success of restoration (Bayraktarov et al. 2016).

Table 4.1. The features of each habitat scored according to their impact on restoration potential. Green shading relates to a feature that may facilitates achieving the restoration goals, orange shading represents medium and red shading denotes that the feature makes restoration relatively difficult. Grey shading represents conditions where different factors (e.g. species or location) may lead to different restoration success. NA indicates that there is scarce or not available information concerning connectivity and spatial distribution (for deep-seas sediment communities). Baltic: Baltic Sea; NEA: North-East Atlantic Ocean; MED: Mediterranean Sea.

Habitat types	Region	Features: Dynamics	Connectivity	Spatial distribution	Structural complexity	Diversity	Vulnerability/fragility	Restoration potential
Shallow soft - Seagrass meadows	MED/Baltic/ NEA			W				
Shallow hard - *Laminaria hyperborea* kelp	NEA			W				
Shallow hard - *Saccharina latissima* kelp	NEA			W				
Shallow hard - Macroalgal forests (shallow)	MED			W				
Shallow hard - Macroalgal forests (deep)	MED			W				
Shallow hard - Coralligenous assemblages	MED			W				
Deep sea - Coral gardens	Azores			W				
Deep sea - Soft sediment communities	MED/CNA		NA	NA				

Legend — Degree: Low, Medium, High, Mixed

NA=Not Available, W=Widespread

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6. ANNEXES

Annex 1 – Table of definitions

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Annex 2 – A list of habitat mapping initiatives, conventions and programs in Europe

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Annex 3 - Describing the MERCES Habitats Catalogues

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Annex 4 – The Catalogues (MERCES_WP1_D1.1_Catalogue_ExistingAndDegradedHabitats_v21.xlsx)

A separate downloadable Excel file

Annex 1: Table of definitions

Table of definitions. IDs starting with "R" indicate definitions dealing with restoration. IDs starting with "H" indicate definitions dealing with different types (or degrees) of habitat degradation.

ID	Term	Definition
R1a	Passive intervention (recovery) (Elliot et al. 2007)	Spontaneous (or natural) regeneration that occurs after the system has being degraded or disrupted and starts to occur when the pressure has been removed. Its success depends on following system properties: recoverability, resilience, adaptation and carrying capacity.
R1a	Recovery (Standish et al. 2014)	The time taken for an ecosystem to return to its pre-disturbance state after a disturbance (Pimm 1984). Units of measurement: time
R1a	Natural recovery (Abelson et al. 2016a)	The process by which an ecosystem returns to a prior state following the cessation of some impact or alteration, is often a slow process that can take decades or even centuries.
R1a	Natural (spontaneous) regeneration	Germination, birth or other recruitment of biota including plants, animals and microbiota, whether arising from colonization or in situ processes. A 'natural regeneration' approach to restoration relies on increases in individuals, without direct planting or seeding, after the removal of causal factors alone, as distinct from an 'assisted natural regeneration' approach that depends upon active intervention.
R1a	Environmental repair (McDonald et al. 2016)	Environmental repair any intentional restorative activity that improves ecosystem functionality, ecosystem services, or biodiversity.
R1b	Partial recovery (McDonald et al. 2016)	The state whereby ecosystem attributes—or not all ecosystem attributes—have improved but do not yet closely resemble those of the reference ecosystem.
R2	Recovery (McDonald et al. 2016)	The process by which an ecosystem regains its composition, structure and functionality relative to the levels identified for the reference ecosystem. In restoration, recovery is assisted by restoration activity – and recovery can be described as partial or full.
R2an1	Active intervention: Rehabilitation and restoration (Elliot et al. 2007)	Rehabilitation is the activity of partially or fully replacing structural of functional characteristics of an ecosystem that have been lost (final state is not expected to be the same as the original one, but simply better than the degraded situation). Restoration is the process of re-establishing, following degradation by human activities, a sustainable habitat or ecosystem with a natural (healthy) structure and functioning.
R2a	Rehabilitation (McDonald et al. 2016)	Direct or indirect actions with the aim of reinstating a level of ecosystem functionality where ecological restoration is not sought, but rather renewed and ongoing provision of ecosystem goods and services.
R2bn1	Active intervention: Remediation and re-creation (Elliot et al. 2007)	Remediation is the activity to rectify and enhance the system ecological value (authors observed that complete restoration is rarely achieved). Re-creation implies the creation for a second time of a system or habitat in order to increase the carrying capacity and the ecological goods and services of the overall system.
R2cn2	Active intervention: Re-introduction, re-establishment, reclamation and replacement (Elliot et al. 2007)	Re-introduction and re-establishment indicate the first and subsequent stages, respectively, in the replacement an ecosystem's structural component (i.e. a structuring species) in sufficient quantities to allow it to regain its ecological functioning.

ID	Term	Definition
R2c	Reconstruction (McDonald et al. 2016)	A restoration approach where the appropriate biota need to be entirely or almost entirely reintroduced as they cannot regenerate or recolonize within feasible time frames, even after expert assisted regeneration interventions.
R2dn3	Active intervention: Mitigation and compensation (Elliot et al. 2007)	Mitigationn3 is the act of making less severe (single stressor is depleted – not removed – and effects are evaluated with an Environmental Impact Assessment). Compensation is making up or make amends for damage. Authors highlight three types: (1) economic compensation (e.g. pay the fisherman), (2) resource compensation (e.g. improve the ecosystem goods and services such as enhance a fishery) and (3) ecological compensation (re-creation of ecosystem goods and services, i.e. 'creative-conservation' such as wetland creation).
R2d	Mitigation (Wikipedia)	Environmental mitigation, compensatory mitigation, or mitigation banking, are terms used primarily by the United States government and the related environmental industry to describe projects or programs intended to offset known impacts to an existing historic or natural resource such as a stream, wetland, endangered species, archaeological site or historic structure. To "mitigate" means to make less harsh or hostile
R2d	Mitigation (Online Biological Dictionary)	Steps taken to avoid or minimise negative environmental impacts. Mitigation can include: avoiding the impact by not taking a certain action; minimising impacts by limiting the degree or magnitude of the action; rectifying the impact by repairing or restoring the affected environment; reducing the impact by protective steps required with the action; and compensating for the impact by replacing or providing substitute resources.
R2e	Active intervention ; habitat enhancement and creation (Elliot et al. 2007)	Habitat enhancement indicates the activity of establishment of an alternative ecosystem increasing the ecological value good and services of the habitat. Habitat creation is an anthropogenic intervention which produces a habitat not previously there.
R2e	Construction (McDonald et al. 2016)	Methods involved in engineering permanent or temporary components that did not occur previously at that site – as distinct from 'reconstruction'.
R2e	Creation (McDonald et al. 2016)	Intentional fabrication of an ecosystem (different from the one previously occurring on a site) for a useful purpose without a focus on achieving a reference ecosystem.
R2e	Designer Ecosystem (McDonald et al. 2016)	Designer Ecosystem an ecosystem that is primarily created to achieve mitigation, conservation of a threatened species, or other management purpose (MacMahon & Holl 2001) rather than achieve the re-establishment of a reference ecosystem.
R2e	Reallocation (McDonald et al. 2016)	It is the conversion of an ecosystem to a different kind of ecosystem or land use primarily for purposes other than the conservation management of local native ecosystems.
R3	Resistance (Standish et al. 2014)	Degree to which a variable is changed following a disturbance (Pimm 1984). Units of measurement: measure of one or more ecosystem state variables (e.g. species composition) before and after disturbance. Measuring resistance does not require knowledge of system specific

ID	Term	Definition
		thresholds
R4a	Resilience (Standish et al. 2014)	The ability of an ecosystem to absorb changes of state variables, driving variables, and parameters, that is, to persist after disturbance (Holling 1973). Also referred to as 'ecological resilience' or 'Holling's resilience' and often confused with 'resistance'. Units of measurement: intensity of disturbance associated with a switch between states (i.e. the threshold; Connell & Sousa 1983) coupled with data to document the switch (e.g. ecosystem attributes such as species composition.
R4a	Resilience (McDonald et al. 2016)	The capacity of a system to absorb disturbance and reorganize while still retaining similar function, structure, and feedbacks (Suding 2011). In plant and animal communities this property is highly dependent on adaptations by individual species to disturbances or stresses experienced during the species' evolution (Westman 1978).
R4b	Helpful resilience (Standish et al. 2014)	Resilience that helps to maintain a pre-disturbance ecosystem state so that it does not cross a threshold. The trajectory of recovery for ecosystems with helpful resilience mirrors the post-disturbance trajectory (i.e. hysteresis is not evident, the 'return' and 'outward' trajectories match; Beisner et al. 2003, Suding & Hobbs 2009)
R4c	Unhelpful resilience (Standish et al. 2014)	Resilience that helps to maintain an ecosystem in a degraded state following a disturbance. Requires management intervention to assist the return of the historic pre-disturbance state due to the presence of a threshold. May be associated with hysteresis
R5	Full recovery (McDonald et al. 2016)	The state whereby all ecosystem attributes closely resemble those of the reference ecosystem (model). It is preceded by the ecosystem exhibiting self-organization that leads to the full resolution and maturity of ecosystem attributes. At the point of self-organization, the restoration phase could be considered complete and the site shifts to a maintenance phase.
1a	Pressure (Elliot et al 2007)	The precise activity leading to change.
1b	Disturbance (Standish et al. 2014)	Any process that effects ecosystem, community, or population structure, and/or individuals within a population either directly or indirectly via changes to the biophysical conditions (Hobbs & Huenneke 1992 and references within). Short-term and longer-term disturbances are often referred to as 'pulse' and 'press' disturbances respectively (Bender et al. 1984) or 'acute' and 'chronic' disturbances (Connell 1997)
2	Threshold (Standish et al. 2014)	Point at which a small change environmental conditions, associated with disturbance, leads to a switch between ecosystem states (Suding and Hobbs 2009)
3n5	Key habitats	No definition found.
4	Ecosystem-services (Abelson et al. 2016a)	The ecosystem-services concept describes and emphasizes the diverse benefits and uses of ecosystems to human society.
5	Cultural ecosystems (McDonald et al. 2016)	Ecosystems that have developed under the joint influence of natural processes and human-imposed organization to provide structure, composition and functionality more useful to human exploitation (SER 2004). Where these remain well within the range of natural variation for

ID	Term	Definition
		the ecosystem (e.g. grassy openings and savannahs traditionally managed by pre-industrial age peoples), they may become the subject of ecological restoration (at least partial recovery). Where they exceed the range of natural variation they may be best managed as historical or production systems and their repair described as rehabilitation.
6	Ecosystem maintenance (McDonald et al. 2016)	Ecosystem maintenance – ongoing activities – applied after full recovery - intended to counteract processes of ecological degradation to sustain the attributes of an ecosystem. Higher ongoing maintenance is likely to be required at restored sites where higher levels of threats continue, compared to sites where threats have been controlled.
7	Environmental repair (McDonald et al. 2016)	Any intentional restorative activity that improves ecosystem functionality, ecosystem services, or biodiversity.
8	Functions, of an ecosystem (McDonald et al. 2016)	The workings of an ecosystem arising from interactions and relationships between biota and abiotic elements. This includes ecosystem processes such as primary production, decomposition, nutrient cycling and transpiration and emergent properties such as competition and resilience. Functions represent the potential that ecosystems will be able to deliver ecosystem goods
9	Indicators of recovery (McDonald et al. 2016)	Characteristics of an ecosystem that can be used for measuring the progress towards restoration goals or objectives at a particular site (e.g. measures of presence/absence and quality of biotic or abiotic components of the ecosystem).
10	Functions, of an ecosystem (McDonald et al. 2016)	The workings of an ecosystem arising from interactions and relationships between biota and abiotic elements. This includes ecosystem processes such as primary production, decomposition, nutrient cycling and transpiration and emergent properties such as competition and resilience. Functions represent the potential that ecosystems will be able to deliver ecosystem goods and services to humans.
11	Local native ecosystem (McDonald et al. 2016)	An ecosystem comprising species or subspecies (excluding invasive non-native species) that are either known to have evolved locally or have recently migrated from neighbouring localities due to changing climates. Where local evidence is lacking, regional and historical information can help inform the most probable local native ecosystems. These are distinguished from 'cultural ecosystems' (e.g. agroecosystems) if the ecosystems have been substantially modified in extent and configuration beyond natural analogues or fall outside the range of natural variation for that ecosystem.
12	Reference ecosystem (McDonald et al. 2016)	A community of organisms and abiotic components able to act as a model or benchmark for restoration. A reference ecosystem usually represents a non-degraded version of the ecosystem complete with its flora, fauna, abiotic elements, functions, processes and successional states that would have existed on the restoration site had degradation, damage or destruction not occurred – but should be adjusted to accommodate changed or predicted environmental conditions. An alternative term for reference ecosystem is 'ecological reference'

ID	Term	Definition
13	Self-organizing (McDonald et al. 2016)	A state whereby all the necessary elements are present and the ecosystem's attributes can continue to develop towards the appropriate reference state without outside assistance (Clewell & Aronson 2013). Self-organization is evidenced by factors such as growth, reproduction, ratios between producers, herbivores, and predators and niche differentiation - relative to characteristics of the identified reference ecosystem.
14	Triggers (recovery) (McDonald et al. 2016)	Natural or applied disturbances or resource fluxes that initiate recovery of plants (e.g. soil disturbance, herbivory, fire, flooding etc.) or placement of key resources to attract and support animals
H1an4	Degraded habitatn4 (Elliot et al. 2007)	Degraded habitat or ecosystem is defined as any system with a poor ecological health.
H1a	Degraded habitat (Airoldi & Beck 2007)	Degradation represents a decrease in condition.
H1a	Degraded habitat (SER 2002)	It pertains to subtle or gradual changes that reduce ecological integrity and health
H1a	Degraded habitat (IUCN, Storch 2007)	A decline in species-specific habitat quality that leads to reduced survival and/or reproductive success in a population e.g. related to changes in food availability cover or climate.
H1a	Degraded habitat (CRM 2006)	Processes of anthropogenic origin that make habitats less suitable or less available to organisms.
H1a	Degradation (Abelson et al. 2016a)	Degradation is the overexploitation of marine ecosystems and natural resources that has led to decline to ecosystem services.
H1a	Degradation – of an ecosystem (McDonald et al. 2016)	A level of deleterious human impact to ecosystems that results in the loss of biodiversity and simplification or disruption in their structure, composition, and functionality, and generally leads to reduction in the flow of ecosystem goods and services.
H2	Damaged habitat (SER 2002)	It refers to acute and obvious changes in an ecosystem.
H3	Destroyed habitat (SER 2002)	A habitat or ecosystem is destroyed when degradation or damage removes all macroscopic life, and commonly ruins the physical environment as well
H4	Transformed habitat (SER 2002)	It is the conversion of an ecosystem to a different kind of ecosystem or land use type.
H5	Habitat loss (Airoldi & Beck 2007)	Habitat loss is a change of habitat distribution
H6	Habitat fragmentation (Airoldi & Beck 2007)	Habitat fragmentation occurs when previously continuous habitats become patchier.

n1 Note that Elliot et al (2007) stress that the terms restoration, rehabilitation, remediation and re-creation have been used interchangeably. They propose that only the term restoration is used for estuaries and coasts.

n2 Elliot et al (2007) recommend that the terms re-introduction and re-establishment are only used in relation to species and that the terms reclamation and replacement should not be used for marine and coastal areas, especially while the term reclamation is still (erroneously) used as an original synonym for the term land-claim (hence an original loss of habitat).

n3 Elliot et al (2007) agree with Bradshaw (2002) that mitigation is not directly connected to restoration although he suggests that it can be an outcome of restoration. Furthermore, Elliot et al (2007) point that the term mitigation should only be used for in situ actions and elsewhere it should be compensation.

n4 Papers provide general assessment of good or bad ecological status to identify the degree of degradation, although the assignment is under great debate and of potential questionable ecological meaning. Although European countries are required to provide assessments describing the ecological status of the habitats occurring within their territories, they are actually far from delivering such results. Thereby most often, as proof of degradation, change in habitat distribution (i.e. habitat loss) is preferred to evaluation of loss in function. Indeed, one may consider habitat loss and fragmentation as proxy of loss in function. Habitat loss has been attested at all spatial and temporal scales.

n5 No definition has been found regarding key habitat. However, Elliot et al (2007) noted that on small scale keystone species and habitat engineers play a central role in restoration. Therefore, if sea-grasses, macroalgae belts, coral reef and oyster or mussel beds might be seen as key habitat because structure by keystone species.

Annex 2: A list of habitat mapping initiatives, conventions and programs in Europe

This is a list to some of the habitat mapping initiatives, conventions and programs in Europa. This list is not comprehensive, there are many others that are not mentioned here. Many countries are relatively active in habitat mapping, but there is not really a single project to refer to, the mapping may be carried out for various purposes, including MPA designation, monitoring, EIA, reporting etc.

- MAREANO - mapping habitats in Norwegian offshore waters, including coral gardens and deep sea areas (2006-ongoing, www.mareano.no/en).
- National program for mapping key habitats along the Norwegian coast, including mapping of seagrass meadows and kelp forests (2007-ongoing) www.miljødirektoratet.no/no/Tema/Miljoovervakning/Kartlegging-av-natur/Kartlegging-av-naturtyper/Marine-naturtyper/

  BALANCE (Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning: 2005-2007), a project developing marine management tools based on spatial planning and cross-sectoral and transnational co-operation. www.vasab.org/index.php/projects/balance
- MESH (Development of a framework for Mapping European Seabed Habitats) produced seabed habitat maps for north-west Europe and developed international standards and protocols for seabed mapping studies (2004-2008, jncc.defra.gov.uk/page-1542)
- VELMU (Finnish Inventory Programme for the Underwater Marine Environment) has since 2004 mapped both abiotic (geological, physical and chemical) and biotic characteristics of the marine environment (www.ymparisto.fi/en-US/VELMU).
- HELCOM (the Baltic Marine Environment Protection Commission - Helsinki Commission) includes Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia, and Sweden and collects data on sea environmental monitoring, sea environmental status, pressures and human activities, biodiversity, maritime & response, and maritime spatial planning. www.helcom.fi/
- In Estonian, Latvian and Lithuanian territorial waters and EEZ in the north-eastern Baltic Sea, extensive mapping of abiotic and biotic components of underwater habitats has been carried out in last 15 years. The most significant mapping programmes were Inventory and Development of Monitoring Programme for Nature Values in Estonian Marine Areas (NEMA), Innovative Approaches for Marine Biodiversity Monitoring and Assessment of Conservation Status of Nature Values in the Baltic Sea (MARMONI), the EU LIFE project Marine Protected Areas in the Eastern Baltic Sea (Baltic MPAs). Map portal for all benthic species distribution data for Estonian waters are found at: loch.ness.sea.ee/gisservices2/liikideinfoportaal/
- In Italy, several mapping projects have been carried out on specific habitats (see also Telesca et al. 2015, Martin et al. 2014) and within the Marine Strategy Framework Directive a national

effort is presently carried out to map within a coordinated framework and well identified protocols *Posidonia*, coralligenous assemblages (both shallow and deep) and maerl beds.

- LIFE+INDEMARES, a project in Spain, has been studying the deep-sea habitats, pelagic species and seabirds and has also analysed the human use of these areas. During the INDEMARES LIFE project (from 2009 to 2014), 10 large marine areas in the Atlantic, Mediterranean and Macaronesian regions were studied with the objective of evaluating and propose their designation as a Natura 2000 sites. www.indemares.es/
- In Croatia, the Ministry of Environmental Protection and Physical Planning initiated in 2002 the development of a GIS database on the distribution of habitat types (www.crohabitats.hr). In the period 2017-2022, an EU funded habitat mapping program will be coordinated by the Croatian Agency for Environment and Nature and will mainly focus in two priority habitats, *Posidonia* meadows and coralligenous assemblages.
- CoCoNet (Towards COast to COast NETworks of marine protected areas, from the shore to the high and deep sea) collected data about habitats occurrence across the Mediterranean and the Black Seas. This effort set the scene to improve spatial prioritization in the Mediterranean and the Black Seas starting from biogenic habitats (e.g. coralligenous assemblages and maerls beds), seagrass meadows (e.g. *Posidonia oceanica*), canopies (e.g. *Cystoseira* spp., *Phyllophora crispa*) and barrens that are considered of critical importance for the two basins. www.nersc.no/project/coconet
- The ADRIPLAN Portal (data.adriplan.eu/layers/?limit=20&offset=120) contains habitat distribution data for two of the focus habitats for ecosystem restoration within the MERCES project: *Posidonia oceanica* (Neptune grass); Maerl beds; and Coralligenous communities (model). The portal also contains data and layers relating to pressures, including environmental conditions and sites for development and excavation.
- The BENTHIS (Benthic Ecosystem Fisheries Impact Studies) project (www.benthis.eu/en/benthis.htm) provides details of the impact of fishing on benthic ecosystems with case studies in the Baltic Sea, North Sea, Western waters, Mediterranean and Black Sea. Results and publications with maps can be found at: www.benthis.eu/en/benthis/Results.htm
- The Ocean Data Viewer (WCMC.io/ODV) contains global habitat distribution data for three of the focus habitats for ecosystem restoration within the MERCES project: Global Distribution of Seagrasses; Global Distribution of Saltmarshes; Global Distribution of Cold-water Corals; and Global Distributions of Habitat Suitability for Cold-Water Octocorals. data.unep-wcmc.org/
- NETMED project produced Mediterranean habitat maps (GIS shapefiles) on the presence of *Posidonia oceanica* seagrass meadows, coralligenous formations, and the number of marine caves (10 x 10 km grid). These maps were considered within an ecoregion-based systematic planning approach (Giakoumi et al. 2013).

Annex 3 : Describing the MERCES Habitats catalogues

The purpose of Annex 2 is to physically describe Annex 3, which is the MERCES Habitats and Degraded Habitats Catalogues database.

The data catalogues are in a simple Excel file entitled MERCES_WP1_D1.1_Catalogue_ExistingAndDegradedHabitats_v20.xlsx

The file consists of 9 separate sheets:

- Sheet 1_Cover page: cover page with citation for the Catalogues and Deliverable D1.1
- Sheet 2_Read me & DoW: description of work and instructions for the contributing partners of the catalogues
- Sheet 3_Catalogue_Habitats: the Habitats Catalogue entries and associated data/information
- Sheet 4_List_Habitats: data entry options and lists of preselected options for various categories of data entries for the Habitats Catalogue
- Sheet 5_Catalogue_Degraded Habitats: the Degraded Habitats Catalogue entries and associated data/information
- Sheet 6_List_Degraded Habitats: data entry options and lists of preselected options for various categories of data entries for the Degraded Habitats Catalogue
- Sheet 7_Regional Seas: regional and sub-regional maps with information on regional seas, their subdivisions, management units, or assessment areas for defining geographical categories entries
- Sheet 8_ EUNIS & EUSEAMAP: European Nature Information System (EUNIS) habitat types hierarchical view and seabed habitats according to EMODNET (European Marine Observation and Data Network) for defining habitat type/feature categories entries
- Sheet 9_Press_ Activ: lists of pressures and activities leading to pressures/concerns with descriptions and examples

A.3. The Catalogues

The entries of the two catalogues are broken down into broad category groups and single categories as below:

A.3.1. Habitats Catalogue

- Data input identifier section: to identify who is putting in the data information including institution name and contact
- Habitat type: identifying the habitats by category, type and main feature

- Other map classifications/categories: listing whether the map source concerns sensitive/ Vulnerable Marine Ecosystem (VME) habitat, area of conservation importance, priority and protected species/habitat or Marine Protected Area (MPA)
- Information: additional information on habitat/features, characteristic/focus species mapped, depth range and general comments
- Region: information on the MSFD region, subregion or other subdivision covered by the source entry
- Source: source/type of the data entry, including full reference and the reference link.

A.3.2. Degraded Habitats Catalogue

- Data input identifier section: to identify who is putting in the data information including institution name and contact
- Habitat type: identifying the habitats by category, type and main feature
- Other map classifications/categories: listing whether the map source concerns sensitive/ Vulnerable Marine Ecosystem (VME) habitat, area of conservation importance, priority and protected species/habitat or Marine Protected Area (MPA)
- Status: providing information on the habitat status (including assessment type and extent of decline), recovery potential, as well as information on relevant reported activities and pressures and suggestions on potential restoration
- Information: additional information on habitat/features, characteristic/focus species mapped, depth range and general comments
- Region: information on the MSFD region, subregion or other subdivision covered by the source entry
- Location of site: details on the coordinates and depth of the mapped degraded habitat of the source
- Source: source/type of the data entry, including full reference and the reference link
- Activities: checklist of 13 major categories of activities explicitly mapped in the reference entry, with any comments provided in a separate column
- Endogenous (manageable) pressures: checklist of 26 major pressures explicitly mapped in the reference entry, with any comments provided in a separate column
- Exogenous (unmanageable) pressures: checklist of 7 major pressures explicitly mapped in the reference entry, with any comments provided in a separate column
- Unspecified activities/pressures: checklist of 5 multiple unspecified activities/pressures that may cause habitat degradation according to the reference entry.

A.3.3 Catalogue entries

There is a total of 577 entries in the two catalogues with data/information provided for most of the categories for each entry. The Habitats Catalogue consists of 376 entries citing 189 different map sources, while the Degraded Habitats Catalogue includes 201 entries derived from 129 sources.