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Multiple pressures and their combined effects in Europe's seas

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Executive Summary

The overarching aims of this report on anthropogenic pressures and their combined effects in Europe's seas are: (1) to provide the first pan-European overview on the potential human impacts and their potential combined effects in coastal and marine waters, for the period of 2011–2016, and (2) to present how these have changed over a longer time horizon, where possible.

The publication is part of a series of the European Environment Agency's (EEA) marine thematic reports that are the building blocks for Marine Messages II, covering a broad range of topics: contaminants, eutrophication, pressures and combined effects, biodiversity, and marine protected areas (MPAs).

The results and conclusions are based on existing data. These are, e.g. data and information reported under the Water Framework Directive, the Marine Strategy Framework Directive and the Data Collection Framework of the Common Fisheries Policy as well as the data collected under the European EMODnet collaboration, Copernicus – Marine environment monitoring service, International Council for the Exploration of the Sea (ICES), regional seas conventions (RSC), and numerous EU-funded projects.

The spatial presentation of pressures and combined effects is shown in a 10 km × 10 km grid. In case of spatially restricted pressures, this causes overestimation of the pressure, but smaller grid cells may also give false signals due to coarseness and gaps in existing data. Combined effects of the pressures represent *potential effects* as the realized impacts are often defined by local characteristics and are very dynamic in time. The chosen approach advises of the relative risks in our marine areas but should not be a substitute to state assessments (e.g. EEA 2019 a, b, c). Technical documentation and details related to the data and assessment methodology are available as On-line Supporting Material (Ch. 6).

Combined effects in Europe's seas

Analysis of the spatial distribution of pressures – resulting from human activities on land or at sea – and the sensitivity of habitats and species gives an overview of the potential effects we exert to the marine environment. During 2011-2016, practically the entire European marine area was under multiple pressures – such as hazardous substances, climate change, underwater noise, non-indigenous species, marine litter and nutrient enrichment. Fishing pressure and seafloor damage are high in the shelf area. In addition, impacts of invasive alien species and physical disturbance are high in coastal areas.

Geographically, the widest stressors in our seas are caused by climate-change, such as increased water temperature and acidification. Human induced underwater noise is also present in many of our seas. The effects of climate change and underwater noise pressures are not yet assessed, but it is clear that these pressures are increasing the sensitivity of marine ecosystems to other pressures. Pressures from spatially restricted activities – such as fishing and seabed exploitation – are also widely spread but show differences among the four marine regions: Baltic Sea, Black Sea, Mediterranean Sea, the North East (NE) and Atlantic Ocean.

The potential combined effects from the activities on seabed, water-column habitats and species are found in most of Europe's marine area (Table 1). The highest potential combined effects are found along coastal areas of the North Sea, Southern Baltic Sea, Adriatitc and Western Mediterranean. The most extensive combined effects in the shelf areas occur in the North Sea and in parts of the Baltic Sea and Adriatic Sea. The analysis did not consider the likely positive influence of good management practices, compensatory measures or protection areas, but a comparison of state assessments of biodiversity have shown, that these measures do not yet adequately compensate for the pressures which degrade habitat quality, affect many of our marine species and put risk on the ecosystem services from the seas (ETC ICM, 2019j). In the areas where management is implemented trends of degradation seem to be reversing.

The assessment of activities and pressures caused by them shows that all marine regions are under multiple, overlapping uses and high levels of pressures; the underlying activities and causes just differ regionally.

The biggest problem in the Baltic Sea is eutrophication. The nutrient inputs to the Baltic Sea result from agricultural land use, but ultimately there are also other reasons such as the ongoing degradation of wetlands, which used to balance the flow rates like sponges. Also, separation of animal and crop farms causes problems in manure placement and higher nutrient leakage.

The Black Sea has a wide catchment area in Central and Eastern Europe, Turkey, the Ukraine and Russia. The big rivers, such as the Danube, Dniester, Dnieper and Bug, bring about larger amounts of nutrients, contaminants and other substances to the sea than to any other marine region in Europe. Wide areas of the north-western coast are seasonally hypoxic. The best-known pressures in the Black Sea are, however, the non-indigenous species which have many times altered the food web and adversely affected the regional economies.

The Mediterranean marine environment is under multiple uses and pressures. Coastal development for tourism increasingly limits habitat and species distribution. Fish stocks are overexploited in the entire basin but especially in the narrow shelf slopes. Non-indigenous species have invaded the region as a result of maritime traffic, the Suez Canal and also escapees from aquaria. In this assessment, we did not have spatial data of marine litter, but litter is perceived to be a problem in all regional seas, especially in the enclosed seas.

In the NE Atlantic, demersal fishing is the human activity which has been recognized as the most impacting pressure in the continental shelf area. Pelagic fish stocks are mainly in a healthy state, but many flatfish and cod stocks are under heavy pressure which is especially concentrated in the southern North Sea, English Channel and the Celtic Seas.

Signs of improvement

The good news from this assessment is that many of the dangerous trends seem to have reversed. We have shown that the northern fish stocks as well as tuna stocks in the open seas show improvement. This can easily be linked with the European and international management actions.

The inputs of nutrients and hazardous substances have decreased over the years in all regions. Though the improvement may become visible only after some time, trends have been broken in many areas where improvement of state has been observed. To maintain positive trends, it is important to maintain the actions as intensity of agriculture and use of new chemicals are likely to continue increasing in Europe. Nonetheless, reports of decreased eutrophication, hypoxia, improved water transparency and decline in contamination have been seen from many areas. Numbers of non-indigenous species are still increasing across Europe's seas, but the speed of new introductions is slowing down.

Concerns for adverse effects and uncertainties

Global warming is causing changes in basic physical and chemical characteristics of marine waters, e.g. temperature, salinity, stratification, oxygen content, but these pressures and their effects may vary between Europe's seas and are difficult to predict. The only widely ice-covered marine region – the Baltic Sea – will certainly meet the effect as has already been seen in the wide reduction of winter-time ice cover. Global warming also facilitates establishment of non-indigenous species and adversely affects the native ones. Due to data gaps, this assessment did not address the effects of acidification, which is another severe pressure resulting from climate change.

Ecosystem effects of pressures in Europe's seas are currently seen in the state of fish stocks, in the state of pelagic and benthic habitats, whereas the historic decline of marine mammals could also be included on the list. About one fifth of the assessed benthic habitats are currently threatened and an additional

11 % are near threatened. The wide spatial scale of our assessment may hide the fact that the greatest effects are in the coastal waters. As many offshore species use coastal waters as their habitat – at least in some phases of their life cycle – our assessment may underestimate the adverse effects of pressures in coastal areas to the wider assessment area. For example, herring stocks are mainly fished from the offshore areas, but their reproduction depends on shallow-water gravel or vegetation. Turtles crawl to shores to lay their eggs, seabirds use cliffs, reefs or wetlands to nest and whales bring their calves into shallow waters to feed. Our assessment suggests that space for these habitats is becoming more and more limited.

Towards sustainable use of Europe's seas

The EU maritime economy is foreseen to further increase leading to increased competition for marine natural resources. In order to be sustainable current and future activities need to be decoupled from the degradation and depletion of the marine ecosystem capital and take place within the current limits of marine ecosystems.

In cases where cause-effect is direct and known, and where management was implemented, pressures on Europe's seas have decreased over time. Combined effects from multiple pressures are currently not considered for the managing and planning of human activities in our seas yet.

Many solutions to achieve the sustainable use of Europe's seas exist already. A good example and a powerful element in the tool kit towards clean, healthy and productive seas are spatial protection measures, such as temporary closures, zoning and no entry areas.

The future of our societies is at stake. It is time to join efforts and implement all our knowledge and use resources to achieve the sustainable use of Europe's seas. This will require profound changes in the way we use our seas, including delivering ecosystem-based management and an unprecedented level of socio-economic adaptation

Table 1 Summary of the extent and temporal trend of pressures in Europe's marine regions and across Europe's seas, based on available information in the period 2011–2016[i]

	Baltic Sea		Black Sea		Mediterranean		NE Atlantic		Europe's seas
Fishing pressure [ii]**;** Chapter 3.2	**68 % of the shelf area**	↓	**3 % of the shelf area**	●	**49 % of the shelf area**	↓	**34 % of the shelf area**	↓	**37 % of the shelf area**
Non-indigenous species [iii]**;** Chapter 3.1	**33 % of the coastline**	↑	**100 % of the coastline**	↑	**98 % of the coastline**	↑	**25 % of the coastline**	↑	**53 % of the coastline**
Human presence/ disturbance; Chapter 3.10	**40 % of the coastline**	↑	**22 % of the coastline**	↑	**38 % of the coastline**	↑	**26 % of the coastline**	↑	**31 % of the coastline**
Physical pressures; Chapters 3.4, 3.5	**71 % of the shelf area**	●	**41 % of the shelf area**	○	**62 % of the shelf area**	○	**58 % of the shelf area**	↑	**43 % of the shelf area**
Eutro-phication; Chapter 3.3	**87 % of the assessed area**	↓	**52 % of the assessed area**	○	**16 % of the assessed area**	○	**13 % of the assessed area**	↓	**59 % of the assessed area**
Contaminants; Chapter 3.6	**96 % of the assessed area**	↓	**91 % of the assessed area**	↓	**87 % of the assessed area**	↑	**75 % of the assessed area**	↓	**85 % of the assessed area**
Marine litter; Chapter 3.7	**Unknown**	○	**Unknown**	○	**Unknown**	○	**Unknown**	○	**Unknown**
Underwater noise[iv]**;** Chapter 3.8	**97 % of the region**	↑	**94 % of the region**	↑	**97 % of the region**	↑	**95 % of the region**	↑	**97 % of the seas**
Climate change; Chapter 3.11	**64 % of the region**	↑	**84 % of the region**	↑	**94 % of the region**	↑	**86 % of the region**	↑	**87 % of the seas**

Legend: Indicative assessment of pressures extent				
Areal extent of pressures (in % area/coastal length)			**Trends**	
(yellow)	**< 10**	**Majority of area/coastal length without pressure**	↓	**Decrease in pressure**
(purple)	**10–50**	**Less than 50 % of area/coastal length under pressure**	↑	**Increase in pressure**
(orange)	**> 50–90**	**More than 50 % of area/coastal length under pressure**	●	**Stable, no trend**
(red)	**> 90**	**Majority of area/coastal length under pressure**	○	**Unknown extent of pressure/unknown trend**

Notes

i. Areal extent of pressures in % of area or coastal length is presented, calculated by each of the regional seas and at the level of the entire of Europe's seas.
ii. Aquaculture is not included in the analysis
iii. Only data on Non-indigenous species cover a longer period: from 1949–2019.
iv. The current analysis is an approximation of the pressure, since by the time of the preparation of this report the effects of noise on marine ecosystems are unknown. The increase of underwater noise is expected due to increase of human activities at sea.

1 Why assess pressures and combined effects in Europe's seas?

KEY MESSAGES:

- Europe's seas, which tend to be perceived as empty and not overexploited by human activities, have historically been used in various ways by people and this use is expected to increase.
- Our use of Europe's seas leads to various pressures, such as pollution by chemicals and litter or seafloor damage and the introduction of non-indigenous species. The combined effects from these pressures are reaching the outermost areas of our seas.
- Despite strong EU marine policy, the use of Europe's seas does not appear to be sustainable yet. Managing human activities in the marine environment following an ecosystem-based approach is key to achieving sustainability.

Oceans and seas are still perceived as the last wilderness of the World, but human influence has already reached them all, from the coasts and the water surface to the deep seafloor. Perception of an endless world has changed in the last 100 years while the impacts of humankind have reached the most remote areas. In vast areas of oceans, human uses and their effects still need to be defined and regulated in practice. Pressures caused by humankind have currently reached the level where the solutions cannot be only dependent on improvement of technology anymore, but require deeper knowledge and cooperation among all stakeholders, as well as a change in our way of life, behaviour and attitudes. We all rely on the seas, so we have an obligation to use them wisely.

The aim of this study is to describe the pressures, caused by human activities, and their potential collective effects upon Europe's marine ecosystems. The assessment is based upon two main pillars: (1) a spatial assessment of multiple pressures and their combined effects, and (2) an assessment of each of the pressures, based on indicators and other relevant information, showing distributions and temporal changes of main pressures acting upon the marine environment, in a holistic manner. The study is one of building blocks for Marine Messages II (EEA, 2019j).

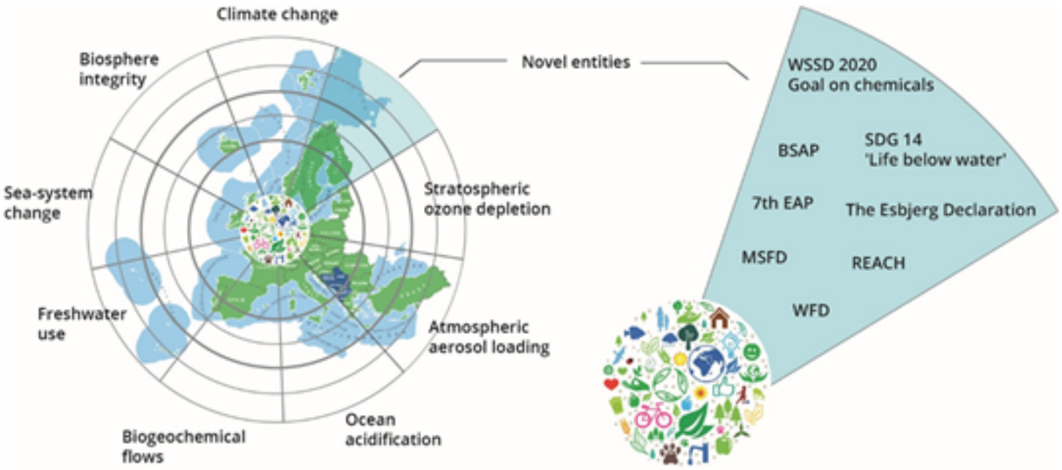
The initial ambition of this report was to assess the cumulative effects of human activities in Europe's seas since that is a requirement in the Marine Strategy Framework Directive. Methodology published in scientific literature and experience in the Baltic Sea were taken as a starting point. One of the steps in the cumulative effects' study requires assessment of synergistic and antagonistic effects from different pressures. At the time of writing this report that was not feasible at the level of Europe's seas – that is the reason that we use the term 'combined effects' and not 'cumulative effects'.

Need for sustainable development within the limits of our seas

Ecosystem-based management is used in contemporary policies for guiding human actions, since it can apply to all decision-making processes that affect the natural world – from those concerned with how we manage our seas, through to the day-to-day decisions of businesses, sea-users and consumers (Figure 1.1). Ecosystem-based management is a way of making decisions in order to manage our activities sustainably. It recognizes that humans are part of the ecosystem and that our activities both affect the ecosystem – for better or worse – and depend on it.

There are several challenges in implementing effective management. A main challenge is to provide evidence of the intensity and distribution of pressures and combined effects that may result from a combination of different human activities. This knowledge is needed to build a solid base for decision-making at local, national, regional and global scales. It can inform the regulation or spatial planning of human activities or the permitting of future activities. In several EU marine regions, legal mandates and agreements to implement ecosystem-based management and spatial plans provide new opportunities to balance uses and protection of marine ecosystems. Sometimes the incentive behind these opportunities is to support sustainable blue economies, but safeguarding less visible biodiversity and ecosystem services can be even more critical.

Figure 1.1: Living within planetary limits — bridging the gap between science and policy. Numerous UN, regional and EU policies address the potential risks of transgressing this boundary



Notes: Example for novel entities, including contaminants, that constitute a planetary boundary. Numerous UN, regional and EU policies address the potential risks of transgressing this boundary. This publication addresses contaminants as one of the pressures in Europe's seas. WSSD, World Summit on Sustainable Development; REACH, Registration, Evaluation, Authorisation and Restriction of Chemicals. WFD, Water Framework Directive. MSFD, Marine Strategy Framework Directive. BSAP, Baltic Sea Action Plan. SDG, Sustainable Development Goal.

Source: EEA 2018d, inspired by Steffen et al. (2015).

Nearly 20 years of EU policy leading the way to sustainability

Success of global commitments depends on regional actions (Table 1.1). The EU Sustainable Development Strategy was published in 2001 (EC, 2001) to identify and develop actions to enable the EU to achieve a continuous long-term improvement of quality of life. This can be achieved through the creation of sustainable communities able to manage and use resources efficiently, able to tap the ecological and social innovation potential of the economy and, in the end, able to ensure prosperity, environmental protection and social cohesion.

The EU Integrated Maritime Policy (IMP; EC, 2010b) is the European vision of the sustainable use of marine waters which aims at promoting blue economies without risking the good status of the marine environment. The IMP seeks a coherent approach to all marine and maritime sectors and policies and holds in its heart the long-term strategy for sustainable Blue Growth and the Maritime Spatial Planning (MSPD; EC, 2014b). While the former supports economic benefits from the sea, the latter is also built on ecological objectives which are set by environmental legislation. The Marine Strategy Framework Directive (MSFD; EC, 2008, 2017a) has been identified as the environmental pillar of the IMP (in MSP, para. 2; EC, 2014b). Even if the IMP is not a legal instrument, the MSFD has set a legal basis for the sustainable development of human activities at sea, since 2008.

As the seas know no boundaries, actions are needed in cooperation with neighbouring countries and globally, since several relevant marine policies are global. The UN 2030 Agenda for Sustainable Development (UN, 2015b) is today's primary commitment to ensure the objective of healthy seas. Under this umbrella, more specific agreements are administered under the International Maritime Organization (IMO).

In this report we will show that there is, however, much to accomplish before our activities can be called environmentally sustainable.

Good environmental status as the basis of sustainability

The MSFD constitutes the first EU legislation specifically devoted to the marine environment. In the core of the directive is the concept of good environmental status (GES), which would be achieved by ensuring sustainable use of marine waters.

MSFD lists ambitious targets, puts in place a robust implementation strategy clearly depicting the responsibilities of each actor, and most importantly it follows an integrated management approach that considers combined impacts instead of regulating specific issues and sectors in isolation.

The EU pieces of legislation having closest connection with MSFD are the Water Framework Directive (WFD; EC, 2000), the Nature Directives (Habitats and Birds), the regulations under the Common Fisheries Policy (CFP; EC, 2013) and the MSPD. There are similarities in the objectives and implementation processes of the WFD and the MSFD. Both Directives together should cover all relevant activities and pressures (sea-based and land-based) to guide progress towards GES.

European fisheries are playing a key role when speaking of sustainable use of marine resources. Since 2003, the EU CFP has taken due account of the fact that most fish stocks in the EU have been overfished for years and there is an explicit provision calling for the CFP to be coherent with the EU environmental legislation. Since, fish stocks live also across the EU marine boundaries, the EU fisheries policy aims to influence fisheries also in neighbouring regions and globally.

Regional cooperation leading the way for coherent management

Europe's marine waters are divided into four marine regions: The Baltic Sea, the Black Sea, the Mediterranean Sea and the NE Atlantic. The regions differ in their natural characteristics like mean depths: 54 m, 1,200 m, 1,500 m and 3,900 m, respectively. Water residence times also differ from the 3,000 years in the Black Sea to the open oceanic environment in the NE Atlantic. The natural characteristics influence how the ecosystems respond to human impacts and therefore the regional perspective is crucial for successful management.

All four regions have established RSCs to protect the marine environment and prevent the region from pollution:

- Convention on the Protection of the Marine Environment of the Baltic Sea Area (the Helsinki Convention, HELCOM),
- the Convention on the Protection of the Black Sea Against Pollution (the Bucharest Convention, BSC),
- Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (the Barcelona Convention, UNEP/MAP),
- Convention for the Protection of the Marine Environment of the North-East Atlantic (the Oslo-Paris Convention, OSPAR).

The common goal of the RSCs is to improve the state of the environment of the European regional seas. The MSFD and the RSCs are developed in parallel, since the MSFD requirement is that Member States should coordinate regionally and with third countries. The regional action plans under the RSCs have adopted the European main environmental principles: ecosystem approach to management, the precautionary principle and polluter pays principle.

Table 1.1 Timeline for selected, non-exhaustive regional policy objectives and targets for achieving good status and sustainable use of European seas

Objectives	Sources	before 2020	2020	2021	2030	beyond 2030
Sustainable use						
Conserve and sustainably use the oceans, seas and marine resources for sustainable development	UN Sustainable Development Goals					
A healthy Baltic Sea environment, with diverse biological components functioning in balance, resulting in good environmental/ecological status and supporting a wide range of sustainable human economies and social activities.	HELCOM					
The vision for the Black Sea is to preserve its ecosystem as a valuable natural endowment of the region, whilst ensuring the protection of its marine and coastal living resources as a condition for sustainable development of the Black Sea coastal states, well-being, health and security of their population	BSC					
Coastal processes are not disrupted by urbanisation, coastal development, and inadequate protection of the integrity of coastal habitats, ecosystems and landscapes, with the result that shorelines remain stable, sea-level rise is accommodated as much as possible by natural adaptation, and habitat fragmentation is minimised.	UNEP/MAP					
Maritime activities						
Environmentally friendly maritime activities	HELCOM					
Sustainable use of commercial fish stocks and other marine living resources	BSC					
Conserve coastal and marine habitats and landscapes.	BSC					
Fisheries exploitation (and harvesting of fish to support agricultural and aquaculture industries) does not exceed sustainable limits, leaving resources to support the complex of ecosystems and allowing for replenishment	UNEP/MAP					
Anthropogenic damage to the seafloor is avoided or minimised, such that the integrity of benthic systems is maintained and benthic/pelagic coupling can continue, as is necessary for healthy marine ecosystems	UNEP/MAP					
Hydrographic conditions are not unduly altered through poorly planned coastal construction, changes to river flows leading to estuaries, or other physical alterations to the coasts and seas	UNEP/MAP					
The Offshore Oil and Gas Industry Strategy	OSPAR					
Pollution						
Baltic Sea unaffected by eutrophication	HELCOM					
Baltic Sea undisturbed by hazardous substances	HELCOM					
Reduce pollutants originating from shipping activities and offshore installations	BSC					
Reduce pollutants originating from land based sources, including atmospheric emissions	BSC					
The Eutrophication Strategy	OSPAR					
The Radioactive Substances Strategy	OSPAR					
The Hazardous Substances Strategy	OSPAR					
Pollution caused by contaminants is minimised so as to prevent disruption of ecology, loss of biodiversity, and negative human health impacts	UNEP/MAP					
Marine litter does not adversely affect the coastal and marine environment, including marine life	UNEP/MAP					
Human-induced eutrophication and increasing hypoxia and anoxia are prevented or minimised through controls on nutrient inputs into coastal waters	UNEP/MAP					
Marine knowledge						
Coastal states and the EEC must not wait for proof of harmful effects before taking action	The Bremen Declaration 1984					
Must adopt a precautionary approach and not wait for full and undisputed scientific proof of harmful effects before taking action	Declaration on the Protection of the Baltic Sea 1988					
Reduce uncertainty in knowledge of the seas and provide sounder basis for marine management	Marine Knowledge 2020					
Share data sets and services between public authorities for purposes of public tasks (INSPIRE+PSI)	Directive 2007/2/EC Directive 2013/37/EU					
Analysis of marine waters for assessment of environmental status	Directive 2008/56/EC (6 years-cycle)					

2 Human activities at sea and the use of natural capital[1]

KEY MESSAGES:

- Seas and oceans hold natural capital; they are essential for meeting people's basic needs and for their well-being and economic prosperity.
- Overall, the EU maritime economy continues to increase – with some sectors declining or stagnating (e.g. North Sea oil extraction), while new sectors (e.g. offshore wind) emerge and grow.
- In the light of the EU's 'Blue economy' objectives, the EU maritime economy is foreseen to further increase. The further development of activities at sea will need to take the environmental aspects fully into account in order to fulfil the EU objective to achieve a sustainable blue economy.

The EU's maritime economy, often referred to as the 'Blue economy', is a powerful driver of socio-economic growth with some untapped potential. It is projected that many ocean-based industries will out-perform the global economy by 2030, both in terms of value added and employment (EC, 2018b).

Coastal and maritime activities include traditional/established sectors, such as fishing, shipping, tourism, aquaculture and the extraction of non-living resources, as well as emerging sectors, such as offshore renewable energies, desalination, blue biotechnology and the extraction of mineral resources specifically in the deep-sea (EC, 2014b, 2017; DG-MARE, 2019b). All these sectors use the natural capital held in Europe's seas one way or another.

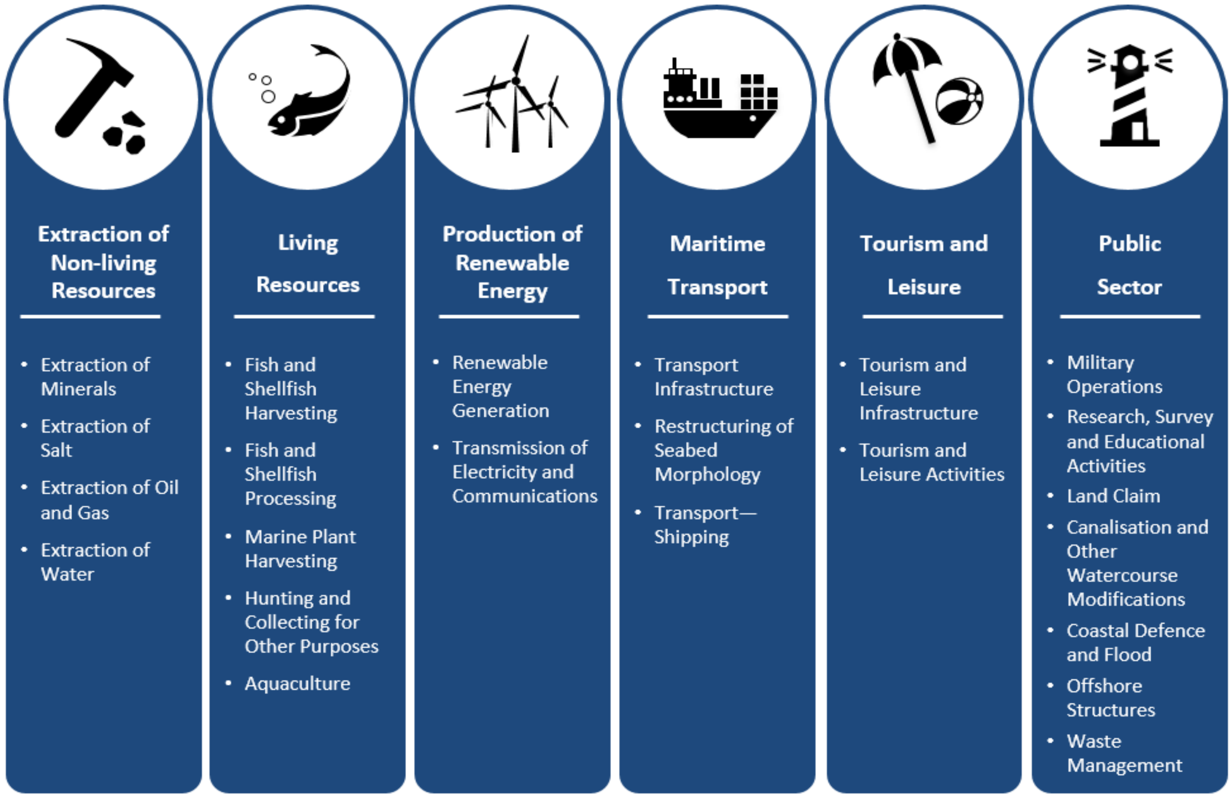
With the available data and information at hand, it can be estimated that in 2017 the EU's maritime economy generated 216,247 million EUR in Gross Value Added (GVA), representing 1.6 % of the total EU economy, and employed roughly 4.9 million people (based on the GVA of all (NACE) economic activities and current prices for the year 2017 (Eurostat, 2019b, c, d)).

This chapter provides an overview of the current state and future outlook of maritime sectors, and associated activities, using Europe' seas. The definition of these sectors and activities builds on the annual economic reports on the EU 'Blue economy' (DG-MARE, 2019b) by using the classifications in the MSFD (Annex III) and the MSPD (Figure 2.1). The resulting sectors are as follows: extraction of non-living resources, living resources, production of renewable energy, maritime transport, coastal tourism and leisure, and the public sector (Figure 2.1).

The chapter starts by outlining the general link between these maritime, and other, uses of the sea and their potential effects on the marine environment and its ecosystems.

[1] The content of this chapter, and related appendix (D), contributed to and was finalised at the same time as the EEA 2019 'Marine Messages II' Report (EEA, 2019j). For this reason, where topics overlap, the text used in both reports could be the same.

Figure 2.1: Classification of EU coastal and maritime activities used in this Report



Notes: 'Marine plant harvesting' here includes macroalgae

2.1 The natural capital held in Europe's seas

The biotic and abiotic assets of the marine environment constitute the natural capital held in Europe's seas, i.e. 'marine natural capital'. Part of this capital is depletable, such as marine ecosystems and the services they can supply to people. These latter assets make up marine ecosystem capital, which is the *biotic* constituent of the natural capital held in the sea. The *abiotic* constituent of this capital is made up of the non-living marine assets, such as fossil fuels; geophysical assets, such as solar radiation, wind and currents; and tides (Figure 2.2; Appendix D: Figure D1) (Maes et al., 2013).

Marine ecosystem services are the final outputs of marine ecosystems that are directly consumed, used or enjoyed by people (Fisher et al., 2009; Haines-Young and Potschin, 2012; Haines-Young and Potschin, 2016; Haines-Young and Potschin, 2018; Maes et al. 2013; EEA, 2015). They include food, building materials, medicines, energy and opportunities for leisure; as well as less tangible ones, such as limited coastal erosion and seawater pollution.

When used by people, these final ecosystem outputs become marine ecosystem services and provide us with a series of important benefits, including nutrition and enhanced physical, mental and emotional health, as well as support to livelihoods and the economy (Appendix D: Figure D2) (Culhane et al., 2019).

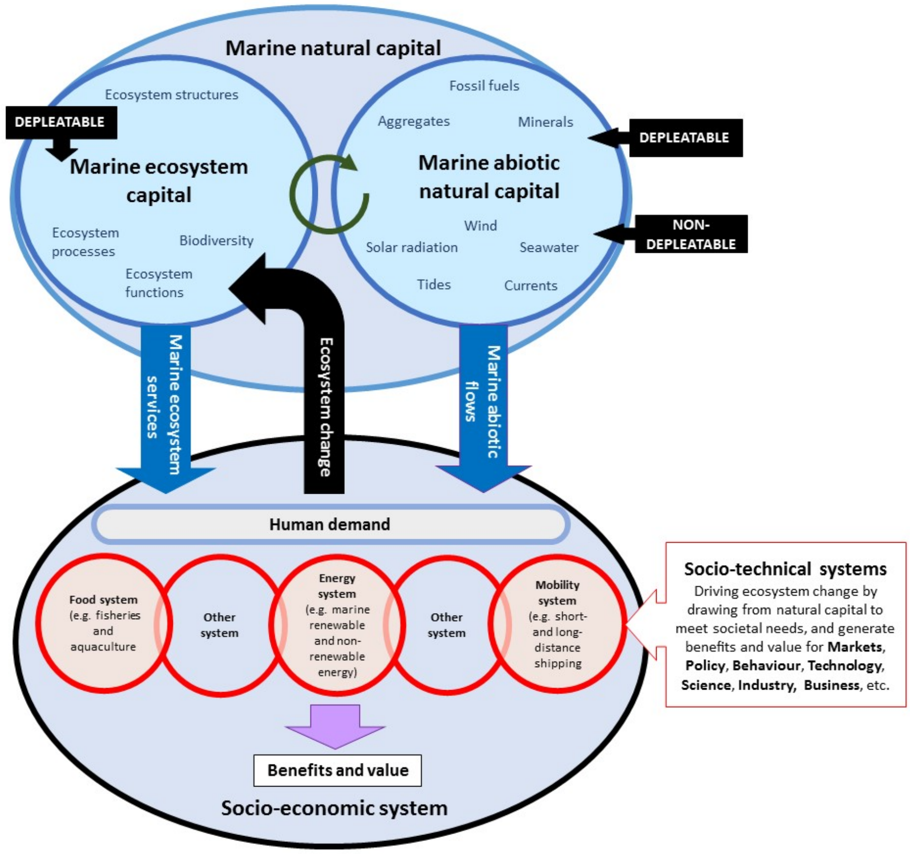
The final ecosystem outputs are generated through the normal functioning of marine ecosystems, which is underpinned by their biodiversity. The structural, biological components of the ecosystem, i.e. marine biota in their habitats, generate these outputs by just being there (Appendix D: Figure D2, Table D1). Marine biota can also generate these outputs by interacting with their surrounding environment using, e.g., physico-chemical elements (such as nutrients, light, and carbon) or feeding on other biota; i.e. through the ecological processes (e.g. photosynthesis) and functions (e.g. primary and secondary production) in which they are involved (Appendix D: Figure D2, Table D1).

2.2 The blue economy can only be sustainable when Europe's seas are clean, healthy and productive

European Commissioner for Environment, Maritime Affairs and Fisheries, Karmenu Vella, stated in 2018 that "*The EU's blue economy is consistently growing over the last decade and the potential for the future is promising. With investments in innovation and through responsible ocean management, integrating environmental, economic and social aspects, we can double the sector in a sustainable way by 2030*" (EC, 2018b).

The EU maritime economy is indeed a thriving economic engine and job creator but, at the same time, it exerts increasing pressure on the marine environment (EC, 2019). Pressures on Europe's seas, from sea- (and land-) based human activities, are driven by our socio-technical systems, which require continuous inputs of marine (and other) ecosystem services and marine (and other) abiotic flows to run (Figure 2.2). In addition, the running of these systems gives rise to undesirable outputs, such as polluting emissions, wastes and energy (e.g. sound, heat), which also put pressure on and impact marine ecosystems, including through anthropogenic climate change (EEA, 2017c) and atmospheric deposition (EEA, 2018b) (Figure 2.2).

Figure 2.2: The constituents of marine natural capital in a socio-economic context



Notes:

- There is no clear-cut boundary between the 'biotic' and 'abiotic' constituents of marine natural capital because, e.g., sand is the substrate of many marine habitats (ecosystem structures). However, this distinction helps to identify and classify such categories, which is important in the context of assessing the condition of marine ecosystems and managing human activities using marine natural capital.
- Marine ecosystems (*sensu* CBD, 2004) and their services, fossil fuels, aggregates, minerals and any other geological deposits are depletable. Seawater, salt, tides and geophysical assets, such as wind, currents and global solar radiation (which is constant above the atmosphere and hence considered a stable asset) are non-depletable.
- Floating solar farms at sea could be a reality by 2021 (Netherlands Organisation for Applied Scientific Research, 2018).
- 'Ecosystem change', caused by the inputs and outputs from running our socio-technical systems, includes change resulting from the use of other natural capital, rather than marine, i.e., that held in terrestrial and freshwater environments – even if not shown in the right hand-side figure.

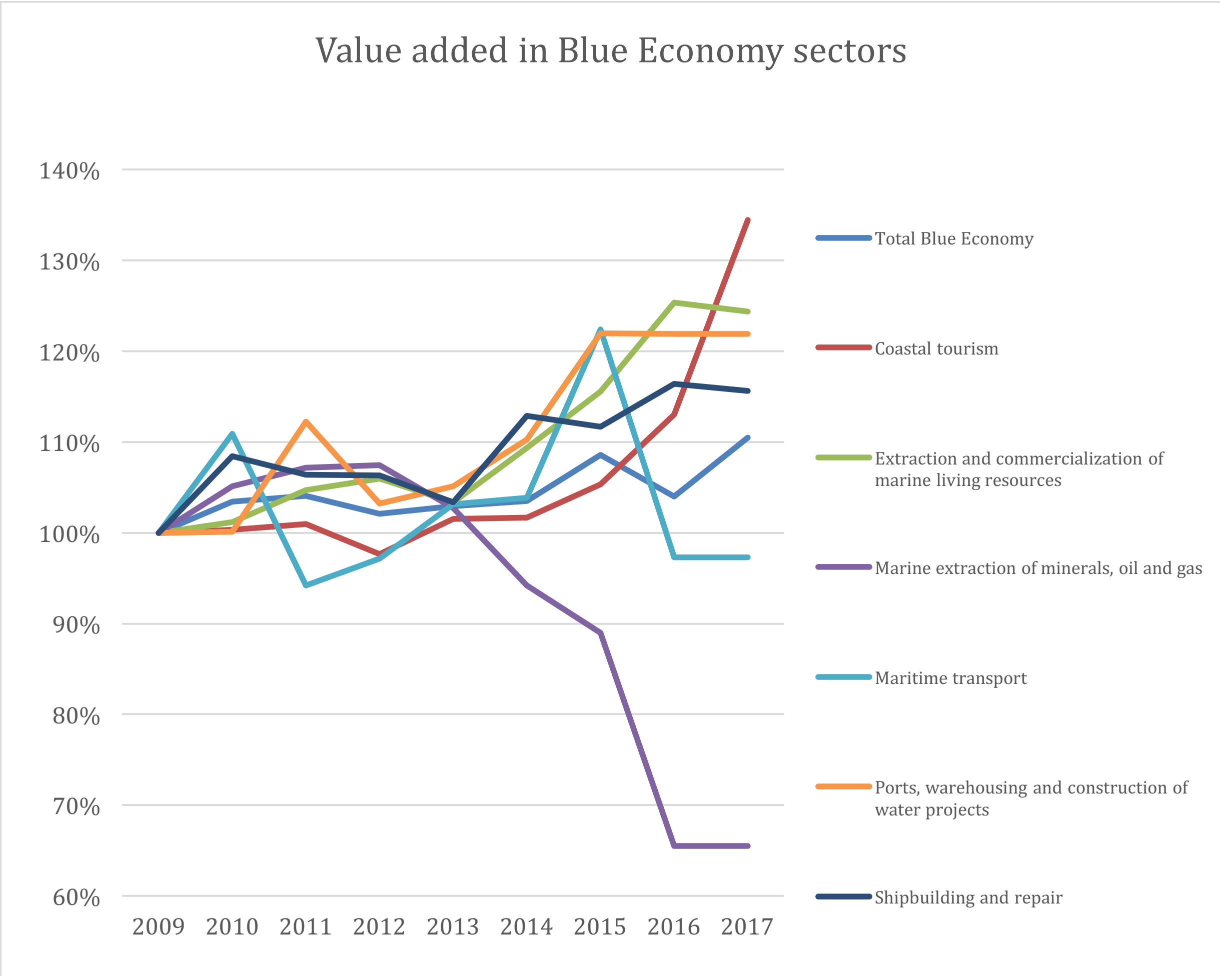
Source: Modified from EEA (2015) and EEA (2018c)

All these inputs and outputs can lead to physical, chemical and biological impacts on marine ecosystems, i.e. to ecosystem change (Figure 2.2, Appendix D: Figure D1) deteriorating their condition and eroding their resilience. In contrast, the sustained supply of marine ecosystem services is based on the self-renewal of marine ecosystems, which occurs naturally if marine ecosystems are used, or affected, within their ecological limits.

The degradation of marine ecosystem structures, processes and functions impairs marine ecosystem capacity for service supply. As a result, the marine ecosystem services, and associated benefits, upon which people and the economy depend are not sustained over time (Appendix D: Figure D2) (Culhane et al., 2019).

More and more industries and people have been turning their attention towards the natural capital held in Europe's seas. There has been a generally increasing trend in the use of these seas by maritime (sub) sectors from 2009 to 2017, such as finfish aquaculture, wind energy production and coastal tourism (Figure 2.3), and this growth is expected to continue for several (sub) sectors (Table 2.1).

Figure 2.3: Evolution of the EU blue economy by sector 2009–2017



Notes: Names of sectors are strictly those from the DG MARE annual blue economy reports, which are defined slightly differently from the ones used in Marine Messages II.

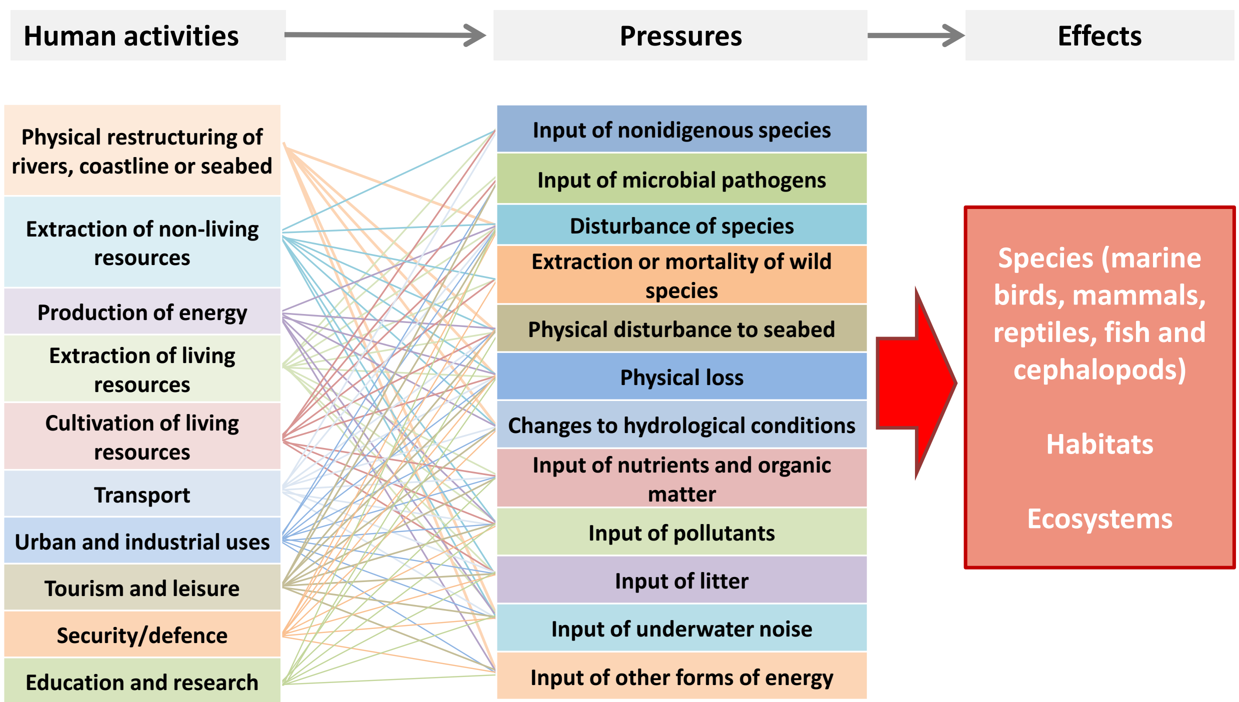
Source: Redrawn from (DG-MARE 2019a; DG-MARE 2019b)

The interconnectedness of the sea means that there are clear linkages between human activities, pressures, marine ecosystems, marine ecosystem services and the benefits we get from these services (White et al. 2013; Gomez et al., 2017; Ivarsson et al., 2017) (Figure 2.2; Figure 2.4; Appendix D: Figure D2).

Because maritime activities depend on the natural capital held in Europe's seas, it is vital that they all use this capital sustainably, so that marine *ecosystem* capital, on which a subset of these activities depends, can be maintained. To note that a greater range of pressures are exerted on marine ecosystems indirectly by human activities using marine abiotic natural capital (e.g. non-living resources) than those activities using marine ecosystem services (e.g. living resources) directly (Table 2.1) (EEA, 2015). This is a key point of concern, since living resources are dependent on good environmental and ecosystem condition, while activities using non-living resources etc. cause pressures on marine ecosystems but are mostly not dependent on their state and neither on the general state of the sea.

Figure 2.4 shows how each of the main human activities (from Figure 2.1) links to multiple pressures on the marine environment and its ecosystems. The diagram does not differentiate between well-managed activities (e.g. the use of less noisy ships for maritime transport, the direct discharge of well-treated wastewater at sea) from non-adequately managed ones. The use of best available techniques (BAT, as phrased in the EU's Industrial Emissions Directive 2010/75/EU) and 'best environmental practices' (BEP) are expected to support the sustainable use of the sea and avoid excessive pressures on the marine environment and its ecosystems (e.g. Styles et al., 2013). This report does not discuss BAT and BEP in detail because the focus is in identifying marine areas where anthropogenic pressures from human activities potentially exceed the limits of the sustainable use of Europe's sea.

Figure 2.4: Human activities, classified strictly following the Marine Strategy Framework Directive (Annex III), and pressures affecting the state of the marine environment



It follows that to be sustainable, as required by the EU 2020 Strategy (EC, 2010a), the blue economy needs to be compatible with having well-functioning marine ecosystems, i.e. marine ecosystems in a condition capable of both sustaining those economic activities at sea relying on marine living resources and maintaining ecosystem resilience. This can only be achieved by decoupling the use of marine natural capital from impacting marine ecosystem capital.

2.3 The use of the natural capital held in Europe's seas

Non-living resources

The extraction of non-living resources sector includes activities related to the mining of marine minerals and aggregates, as well as the extraction of salt, oil, gas, and seawater for desalination. Overall, these activities generated 22881 million EUR in GVA and employed an estimated 166 thousand people in 2017 (COGEA et al., 2017; DG-MARE, 2019a, b) (Table 2.1).

Marine mineral and aggregate extraction consists of the dredging of gravel, sand, clay and even mud (for, e.g., cosmetic purposes and spas) as well as quarrying ornamental and building stone, limestone, gypsum, chalk and slate. The top three producers in 2014 were the Netherlands (14 million tonnes), the UK (12 million tonnes) and Germany (10 million tonnes). The licensed area covers up to 3,000 km^2 of the NE Atlantic and Baltic Sea. No estimates are available for the Mediterranean and Black Sea. The marine aggregate production has continuously increased since 1970s, but some decline is visible in recent years and is predicted in the future (Figure 2.5. a; Table 2.1; DG-MARE, 2019b). In addition, the amounts of marine sediment dredged annually for port and navigation maintenance are currently about 200–250 million tons, mostly in the NE Atlantic and this amount has increased since 2008 (Figure 2.5.b; OSPAR, 2010; ICES, 2017a). No EU-wide information is available for sand extraction. Mining of metals for commercial purposes is expected to expand in the future because, in the coming decades, the world's precious metals, including cobalt, copper and zinc as well as rare earth metals, is expected to increasingly come from the seafloor (Table 2.1). Mining of manganese nodules has been done on abyssal plains, cobalt-rich crusts on seamounts and polymetallic sulphide deposits adjacent to hydrothermal vents, but deep-sea mining activities have so far occurred outside European boundaries and are still exploratory due to their low cost-effectiveness (Ramirez-Llodra et al., 2011). There are, however, exploratory applications in the Tyrrhenian Sea and Norwegian Sea (ECORYS, 2014); although scientists and environmental NGOs have warned of the risk of irreversible and significant environmental impacts of deep-sea mining. They also argue that its socio-economic benefits are uncertain and short term, and point at the overall threat of deep-sea mining to global sustainability and the need to use existing sustainable alternatives instead (SAR, 2017).

Extraction of salt is done by evaporating water in open ponds. The sector is rather small in Europe and occurs mainly in the Mediterranean Sea. Total production in the EU was 1.4 million tonnes in 2014 (almost all in Spain and Portugal). Other countries where the activity takes place are France, Italy, Greece and the UK. Salt production in the coming decade is expected to continue to move away from the EU to the Middle-East, Asia-Pacific and South America due to available land, transfer of technologies, and less stringent political and environmental conditions (Sedivy, 2017) (Table 2.1).

Extraction of oil and gas, including infrastructure, started in European seas in the 1960s. The North Sea is the most intensive oil drilling sea area in the world with 173 active rigs, but the activity covers also the Levantine Sea, Adriatic Sea, Black Sea and Baltic Sea (Lee et al., 2015). The top EU offshore oil producing countries in 2012 were the UK (75.4 %), Denmark (18.2 %) and Germany (2.1 %), while the top EU offshore gas producing countries included the UK (54.6 %), the Netherlands (25.2 %) and Italy (8.1 %) (JRC, 2015). Norway's offshore oil production in 2012 was 122 million tonnes, while gas production was 108 million tonnes of oil equivalent (Norsk Petroleum, 2017). However, overall, EU oil and gas extraction activities are declining (Figure 2.5.c, d). Offshore oil and gas production in the EU is expected to decrease significantly to 21.7 million tons of oil (-88 %) and 135 million tons of oil equivalent in 2050 (-21 %), respectively (DNV-GL, 2017) (Table 2.1). This is due to the reserves in EU waters decreasing, rather than the demand (DNV-GL, 2017); although a dramatic reduction in the use of hydrocarbons is expected in order to meet EU commitments to the 2015 Paris Agreement to limit the extent of the climate emergency.

Seawater extraction. A key aim of seawater extraction is desalination, which produces freshwater for drinking or irrigation purposes (Veerapaneni et al., 2007; Parise, 2012). As desalination occurs predominantly in EU Member States with limited access to freshwater, such as Spain, Portugal, Greece, Italy, Malta and Cyprus, it is likely that desalinated water will become a competitive alternative to potable water production (IWA, 2016) (Table 2.1). Sea water is also used for the cooling of coastal power plants and for processes in many other industries (e.g. liquefaction and regasification of LNG).

Living resources

The extraction of living resources sector includes activities related to fish and shellfish harvesting and processing, marine plant and algae harvesting, hunting, and collecting marine biota for other purposes and aquaculture. Overall, these activities generated 21 553 million EUR in GVA and employed an estimated 591,000 people in 2017 (DG-MARE, 2014, 2019a, 2019b) (Table 2.1).

Fish and shellfish harvesting. In 2014, the EU fishing fleet comprised 81 500 vessels of which 17,860 were inactive. The fleet had a combined gross tonnage of 1.6 million tonnes and a total engine power of 6.4 million kilowatts. Between 2008 and 2014, the EU fleet capacity decreased at an average rate of 2 % annually, in terms of vessel numbers, kW and in gross tonnage. The live weight of landings has decreased by 21 % between 2000 and 2015 (Eurostat, 2019a) but this has stabilized between 2008 and 2014 (Figure 2.5.e).

Marine (wild) plant and macroalgae harvesting means the collection of wild plants and macroalgae by machine or hand. Production in the EU has increased by 27 % from 73,501 tonnes in 2008 to 93,277 tonnes in 2014 (FAO, 2017). Macroalgae are used for the production of alginic acid with gelling and bio-active characteristics for the purposes of food processing and pharmaceutical industry. In agriculture, algae and algae-based products are also used as fertilizer and animal feed. In 2014, Norway produced 154,230 tons, France 58,812 tons, Ireland 29,600 tons and Spain 2,154 tons of macroalgae (FAO, 2017). Wild marine plants, like those in saltmarshes and seagrasses, have many uses such as for cosmetics (e.g. *Salicornia*) and insulating material (e.g. *Posidonia oceanica* pellets) (see review in Culhane et al., 2019).

Hunting is an activity that is practiced, under certain conditions, and licenced differently across different European countries, and statistics of seabird hunting are not collected European wide. Hunting and trapping of sea birds are common in many Mediterranean countries (Barca et al., 2016). HELCOM estimated that the annual bird game caught in the Baltic Sea is 680,000 mallards, 100,000 Eurasian teals, 37,000 common eiders, 36,000 Eurasian wigeons, 16,200 long-tailed ducks, 15,400 goldeneyes, 8,400 tufted ducks, 8,200 great cormorants, 6,200 common scoters, 3,500 goosanders and 2,200 velvet scoters (HELCOM, 2018a). Part of these bounty is shot on inland breeding areas but the species over-winter in the marine area. Seal hunting is permitted, under certain conditions, in Denmark, Estonia, Finland, Sweden and Norway. In 2016, circa 460 grey seals, 180 harbour seals and 270 ringed seals were shot in the Baltic (HELCOM, 2018a).

Whaling is not allowed in the EU due to legislation protecting cetaceans. It is, however, practiced in other European counties, namely Norway, Iceland, Greenland and the Faroe Islands. Norwegian whalers killed 660 minke whales in 2015 and 432 in 2017. In Iceland, 706 endangered fin whales have been killed since 2006; typically, 130–160 per year. Some tens of minke whales are killed annually in Iceland, since 2003. Faroe Islands practice a traditional whaling where about 800 long-finned pilot whales and some Atlantic white-sided dolphins are killed each year. Faroese legislation also allows for hunting of bottlenose dolphin, white-beaked dolphin and harbour porpoise (Olsen, 1999; IWC, 2019).

Marine aquaculture production has been increasing in Europe since 1990. However, this growth is due to the Norwegian production, while the EU contribution has been stable (EEA, 2019d; Figure 2.5.f). Marine aquaculture in EEA countries has increased by 198 % from 0.855 million tonnes in 1993 to 2.548 million tonnes in 2015 (EEA, 2019d) of fish, shellfish and algae. The major producers were Norway

(46 %), followed by five EU Member States: Spain, UK, France, Italy and Greece, making up 76 % in weight of the EU aquaculture production (STECF, 2016; EEA, 2019d). In terms of weight, the main marine aquaculture species produced in Europe in 2015 were Atlantic salmon (1.5 mill t), mussels (496,000 t), seabass (144,000 t), gilthead seabream (134,000 t) and rainbow trout 107,000 t) (EEA, 2019d). The volume of farming of macroalgae is negligible compared to fish and shellfish (< 400 t).

Collecting **marine bioresources** for biotechnological purposes is a growing sector (Figure 2.5.g). Such blue biotechnology includes marine bioprospecting of sponges or planktonic bacteria and algae for, e.g., the development of medicines; the use of marine biota in bioremediation and as bio indicators; and genomics in aquaculture (COGEA et al., 2017).

Regarding future developments of the living resources sector, the combined growth rate of wild capture fish and shellfish and marine aquaculture in the EU between 2013/2015 and 2025 is expected to be modest, with a 2.3 % increase. However, aquaculture on its own is expected to have a growth of 8.9 % during this period (FAO, 2018a) (Table 2.1).

Production of renewable energy

The marine renewable energy production sector includes activities related to offshore wind, wave, tidal, and thermal and other ocean energy production, as well as the transmission of electricity and communications. Overall, these activities generated 869 million EUR in GVA and employed an estimated 185 thousand people in 2017 (Douglas-Westwood Ltd, 2005; COGEA et al., 2017; DG-MARE, 2019b) (Table 2.1).

Offshore wind energy production has seen a boom since the 2000s (Figure 2.5.h). Most offshore wind farms are in the North Sea and Baltic Sea (GWEC, 2017; WindEurope, 2018). At the end of 2016, Europe's combined installed capacity reached 12,631 MW, across a total of 3,589 grid-connected wind turbines. Including sites under construction, 12 European countries had established 91 offshore wind farms, most of which can be found in the UK (30 farms), Denmark (18), Germany (16), and Sweden (7) (4C Offshore, 2017). There are increasing trends in the size and capacity of the turbines, and their distance from shore. Turbines are placed in average at 29 meters' depth and 81 % of the turbines have monopoles drilled to the seabed (WindEurope, 2018). The world's first floating wind farm was installed off the coast of Scotland in 2017 and is currently in operation. Projections for 2020 foresee 43,000 MW of the total installed capacity of offshore wind, generating roughly 3 % of the EU's total electricity consumption (EC, 2014 a, c). Offshore wind grew 18 % in 2018 and is expected to keep on growing reaching up to 100 GW in 2030 according to the most ambitious scenario (WindEurope, 2019) (Table 2.1). The sea-floor area which is lost from the construction sites is relatively limited (~10 km^2 excl. the connecting cables).

Tidal, wave and ocean energy utilize kinetic, temperature and salinity properties of the ocean. The majority of the EU installed capacity is in France (240 MW), with the UK and Portugal contributing significantly less with 3 MW and 1 MW, respectively (EC, 2017b). The UK is currently, however, constructing the world's first tidal lagoon power plant called the 'Swansea Bay Tidal Lagoon' with a capacity of 320 MW. Currently, tidal, wave and ocean energy generate 0.02 % of the EU-28's total electricity generated from renewable sources in 2015 (Eurostat, 2017a). These energies, however, are more suitable to marine environments with regular tides and steady waves, i.e. the North-East Atlantic Ocean, often not found in the Mediterranean Sea and Black Sea. Though contentious, some projections foresee installed ocean energy capacity in the EU reaching 3 600 MW by 2020 (EC, 2016), while others project 665 MW by 2020 (JRC, 2017) (Table 2.1). As offshore renewable energies continue to grow, more and longer cables and pipelines will be needed to reach the further offshore farm sites (COGEA et al., 2017).

Cables for **communications and electricity transfer** are laid on or buried under the seafloor across all Europe's seas (https://www.submarinecablemap.com). A rough areal estimate of cables in, e.g., the NE

Atlantic is 5–10 km^2 (Benn et al., 2010). Subsea telecommunication cables are the main method for worldwide communication, transmitting over 95 % of all international communication traffic (Carter and Burnett, 2015). Laying of subsea cables will likely increase with the expected increase in wind energy production (Table 2.1). Telecommunication cables are also expected to expand into new territories, especially in thawing Arctic regions, as the Russian Optical Trans-Arctic Submarine Cable System (ROTACS) is planned to link London and the Russian Arctic to Tokyo, with branches to South Korea and China (Carter and Burnett, 2015).

Maritime transport

The maritime transport sector includes activities related to transport infrastructure development and maintenance, restructuring of seabed morphology (maintenance of shipping lanes), and shipping. Overall, these activities generated 80,277 million EUR in GVA and employed an estimated 1,294 people in 2017 (DG-MARE, 2019a) (Figure 2.5.i; Table 2.1).

Shipping provides a means to move large amounts of goods and commodities between countries at a significantly cheaper price than air or road transport. In 2015, roughly 3,800 million tonnes of goods and commodities were handled in the EU-28 ports, the majority of which were handled in The Netherlands (approximately 600 million tonnes), the UK (500 million tonnes), as well as Italy and Spain (400 million tonnes) (Eurostat, 2017b). Passenger visits amounted to over 395 million people in 2015, the majority of which were in Italy (18 %) and Greece (17 %), followed by Denmark (11 %), Germany (8 %) and Sweden (8 %) (EEA, 2016; Eurostat, 2017c). In 2014, 123 cruise ships operated in Europe's seas (CLIA, 2015). Although the growth of the sector has been huge since the 1950s, global growth trends are slow and are still recovering from the 2008 economic crisis (UNCTAD, 2015). Slow growth is attributed to the sector's struggle with overcapacity, price wars, low freight rates as well as changes in demand from developing countries like China (Paris, 2017; UNCTAD 2015).

Short sea shipping (covering relatively short distances within a continent in contrasts with intercontinental, cross-ocean deep sea shipping, (EC 1999) is the main maritime transport mode for the EU coastal Member States, with over 1,864 million tonnes of goods handled in the EU in 2017, a slight increase (0.5 %) from 2016 (EC, 2015; Eurostat, 2019d). Overall, the sector has remained relatively stable, but is expected to increase by about 2 % annually in the Baltic Sea and in the Mediterranean Sea, while the North Sea and, more widely, the NE Atlantic Ocean are expected to have the lowest increases in short sea shipping in the future (EC, 2015) (Table 2.1).

More than 1,200 **commercial ports** in the EU's 23 coastal Member States are key nodes of the global trade network and handle around 75 % of the EU's cargo trade with third countries and over 33 % of intra-EU freight transport (ECA, 2016). In 2017, roughly 3,961 million tonnes of goods and commodities were handled in the EU-28 ports, while passenger visits amounted to over 414 million people (EEA, 2016; Eurostat, 2019b, 2019c) (Table 2.1).

Tourism and leisure

The coastal tourism and leisure sector includes activities related to the establishment and running of infrastructure as well as to accommodation, transport and retail sale of goods/other expenditure. The latter three sub-sectors generated 69,423 million EUR in GVA and employed an estimated 2.267 million people in 2017 (DG-MARE, 2019a) (Figure 2.5.j; Table 2.1). Tourist expenditure in those sub-sectors is associated to beach and coastal-based activities, such as swimming and coasteering, and water-based or sport-type activities, such as sailing scuba-diving, recreational fishing, cruising and marine wildlife watching (EC, 2019e).

As the coastal tourism infrastructure sub-sector is linked to various other sectors (e.g., construction, hospitality and port management), it is difficult to estimate the GVA and employment numbers associated with it (hence no information is provided Table 2.1).

The value of the coastal tourism sector is about one fourth of the entire maritime sector (COGEA et al., 2017). The EU received over 482 million of over 1,240 million international tourist arrivals worldwide (EU and non-EU tourists) in 2016 (Eurostat, 2019e). Coastal areas are very popular tourist destinations, where nearly half (46 %) of all nights spent in tourist accommodation tend to occur there (Onofri and Nunes, 2013; Eurostat, 2017h).

Between 2004 and 2014, the EU-28 tourist arrivals increased by approximately 80 % (Eurostat 2015). Coastal tourism is expected to grow in the coming years as more people, both within the EU and internationally, spend increasing portions of their income travelling. Expected visitors to coastal areas are estimated to increase by 2–3 % in 2020, with increases in coastal tourists ranging between 504–531 million people (EC 2016b; ECORYS 2013) (Table 2.1). Global growth projections for the cruise shipping industry expect 30 million passengers for 2019, with increasing interest from younger generations (CLIA, 2018).

Growth in the industry will require additional public service support and physical infrastructure in and around the EU's coastline to cope with more visitors (e.g. roads, airports, hospitals, hotels, sanitation and waste disposal, port facilities, restaurants and supermarkets).

Public sector

The public sector includes activities related to military operations; research, survey and education; land claim; canalisation and other watercourse modification; coastal defence and flood protection; offshore structures; and waste treatment and disposal. Overall, these activities generated 31 305 million EUR in GVA and employed an estimated 372 thousand people in 2017 (DG-MARE, 2019a, b) (Table 2.1).

The **security and defence sector** includes defence and training operations in the marine environment. It is expected that the currently declining trend of government expenditures will be reversed in the coming years due to recent geopolitical developments (DG MARE, 2019b).

The same increasing trend is expected for **education and research** in the domain of marine and maritime sciences (MareNet, 2003). Different institutions provide a range of courses, products and services based on various disciplines, such as marine ecology, ecotoxicology, oceanography and governance (DG-MARE, 2019b). The EU dedicated over 238 million EUR for maritime research under the Horizon 2020 programme for the 2018–2020 funding period (EC, 2018a).

The **physical restructuring of the coastline and seabed** by public authorities aims at protecting Europe's coasts from floods and erosion. Relevant activities include dune and cliff stabilisation through construction of seawalls, dikes, revetments and bulkheads (DHI, 2017), as well as the use of natural-based solutions, such as restoring coastal wetlands due to the role in reducing coastal flooding (Möller, 2019). Almost 85 % of the coastal protection expenditure (1998–2015) was spent in five countries to protect Europe's coasts against flooding and erosion (the Netherlands, Germany, UK, Spain and Italy) (PRC, 2009).

Coastal protection is one of the premier challenges for the public sector as this relates closely to the trends in (relative) sea level rise and hazards related to the increased magnitude of storms. Rising extreme sea levels linked to the climate crisis and continued socio-economic development in coastal zones will lead to increasing future flood risk along the EU coastline. Flood defence structures need to be installed or reinforced to withstand increases in rising extreme sea levels that range from 0.5 to 2.5 m by

2100 to keep future coastal flood losses constant relative to the size of the economy. Otherwise, and in the absence of further investments in coastal adaptation, the expected annual damage of € 1.25 billion under present climate conditions is projected to increase by two to three orders of magnitude by the end of the century, ranging between € 93 and € 961 billion (in today's money). The magnitude of the difference in the projections is due to not only the climate scenario but also on the socioeconomic scenario used (Vousdoukas et al., 2018).

Oil and gas pipelines along the seafloor have been built in all EU marine regions. The NordStream I and II gas pipelines route 1,200 km across the Baltic Sea from the Russian Gulf of Finland to Germany. BalticConnector is a shorter one from Finland to Estonia. In the North Sea, there are 8 oil or natural gas pipelines (BBL, CATS, Europipe I, FLAGS, Franpipe, Frigg UK, Fulmar Gas, Interconnector, Langeled, MIDAL, NOGAT, Norpipe, SAGE, SEAL, Statpipe, Tyra West –F3, Vesterled, Zeepipe). In the Medi–terranean Sea, the Greenstream pipeline routes from Libya to Italy, the Maghreb–Europe Gas Pipeline from Morocco to Spain, Medgaz from Algeria to Spain, Trans-Mediterranean Pipeline from Tunisia to Sicily, and two pipelines are under construction (GALSI from Tunisia to Sardinia and Trans Adriatic from Albania to Italy). The EU-initiated Southern Gas Corridor pipeline has a small part built across the Sea of Marmara. In the Black Sea, Blue Stream crosses the eastern basin from Russia to Turkey.

Waste treatment and disposal, i.e. waste management, here focuses on measures taken by public authorities in order to prevent untreated or partially treated urban wastewater being discharged directly into the marine environment. Under the EU Urban Waste-Water Treatment Directive, the most important measure is the requirement to collect and treat wastewater in all settlements and areas of economic activity with a population equivalent larger than 2,000. However, these measures are not always implemented and/or successful (ECJ, 2018). In Norway, Sweden and Finland the connection rate to the treatment facilities is 80 %; in Germany, Denmark, and The Netherlands 77–96 % of the population is connected; in Italy, Spain and Greece the connection rate is 88–94 %; while Malta has a connection rate of 13 %. In Estonia, Poland and Lithuania 50–60 % of the population is connected to tertiary treatment, while in Bulgaria and Romania 29–64 % is connected to a wastewater treatment facility (EEA 2015a). The sector faces several challenges, such as insufficient capacity at peak times of the year, inadequate treatment types (ECJ, 2018) as well as control (or lack of thereof) of contaminants (EEA, 2018a). Wastewater effluent contains pharmaceutical residues as treatment plants are not designed to remove the increasing amount of pharmaceuticals contained in wastewater (Hofman, 2019). Other challenges include control of micropollutants, impacts of anthropogenic climate change on wastewater treatment and the right pricing of water services and public understanding (OWAV, 2019). Regarding micropollutants, wastewater effluent also contains microplastics (Kay et al., 2018) and so does sewage sludge (the by-product of waste water treatment) (Kay et al. 2018; UKWIR, 2019). The latter can be used as a fertiliser and would, thus, remain in the aquatic environment through agricultural land run-off (Kay et al., 2018).

Table 2.1 EU coastal and maritime activities; their estimated economic value (GVA); number of people employed; expected future trends; current dependency on marine natural capital constituents; and current pressure on marine natural capital constituents (years vary)

Theme ('sector')	Activity	GVA (million €)	Employment (thousands); % (of total employees)	Expected trends [(*)]	Main dependence on		Main pressure on	
					Marine *abiotic* natural capital	Marine *biotic* natural capital	Marine *abiotic* natural capital	Marine *biotic* natural capital
Extraction of Non-Living Resources	Extraction of minerals[(1) (2)]	5,660 (2.5 %)	100.6 (2.1 %)	GVA: → Empl: →	✓		✓	✓
	Extraction of salt[(2)]	40 (< 1 %)	0.7 (< 1 %)	GVA: → Empl: →				
	Extraction of oil and gas[(1)]	17,181 (7.6 %)	62.8 (1.3 %)	GVA: ↘ Empl: ↘				
	Extraction of water[(3)]	---	3.8 (< 1 %)	GVA: ↗ Empl: ↗				
Living Resources	Fish and shellfish harvesting[(1)]	4,622 (2 %)	151.2 (3.1 %)	GVA: ↗ Empl: ↘	✓	✓		✓
	Fish and shellfish processing[(1)]	14,062 (6.2 %)	347.5 (7.1 %)	GVA: ↗ Empl: →				
	Marine plant and algae harvesting	---	---	---				
	Hunting and collecting for other purposes[(4)(3)]	9 (< 1 %)	17 (< 1 %)	GVA: ↗ Empl: ↗				
	Aquaculture[(1)]	2860 (1.3 %)	74.9 (1.5 %)	GVA: ↗ Empl: ↘	✓	✓		✓
Production of Renewable Energy	Renewable energy generation[(2)(3)]	684 (< 1 %)	185.3 (3.8 %)	GVA: ↗ Empl: ↗	✓		✓	✓
	Transmission of electricity and communications[(5)]	185 (< 1 %)	---	GVA: ↗ Empl: ↗				
Maritime Transport	Transport infrastructure[(1)]	31,215 (13.8 %)	508.9 (10.4 %)	GVA: ↗ Empl: ↗	✓		✓	✓
	Restructuring of seabed morphology[(1)]	3,225 (1.4 %)	65.2 (1.3 %)	GVA: ↘ Empl: ↘				
	Transport—shipping[(1)]	45,837 (20.3 %)	719.9 (14.8 %)	GVA: ↗ Empl: →				
Coastal Tourism and Leisure	Tourism and leisure infrastructure	---	---	---	✓	✓		✓
	Tourism and leisure activities[(1)]	69,423 (30.7 %)	2,267.0 (46.5 %)	GVA: ↗ Empl: ↗				
Public Sector	Military operations[(2)]	28,769[(**)] (12.7 %)	360.7 (7.4 %)	GVA: ↗ Empl: ↘	✓	✓	✓	✓
	Research, survey and educational activities	---	---	---				
	Land claim[(2)]	1,390[(**)] (< 1 %)	5.7 (< 1 %)	GVA: ↗ Empl: →				
	Canalisation and other watercourse modifications	---	---	---				
	Coastal defence and flood protection[(2)]	1,145[(**)] (< 1 %)	5.4 (< 1 %)	GVA: ↗ Empl: →				
	Offshore structures	---	---	---				
	Waste treatment and disposal	---	---	---				
TOTAL		226,307	4,876.5					

Notes:

[(*)] Trends are a best estimate based on available sources and expert opinion.

[(**)] Data represents public expenditure (million €) in 2014, extracted from (COGEA et al., 2017)).

[(1)] Data extracted from the EU's Blue Indicators Tool (DG-MARE, 2019a) on 29 May 2019, but for the 'Extraction of oil and gas', IOGP estimates 'well above 500 000 jobs' (pers. comm., unpublished data).

[(2)] Data extracted from COGEA et al (2017).

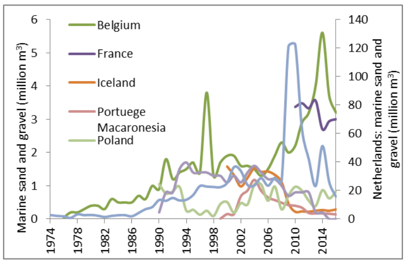
[(3)] Estimate taken from EC (2019d).

[(4)] Estimate taken from EC (2016a).

[(5)] Data extracted from Douglas-Westwood Limited (2005).

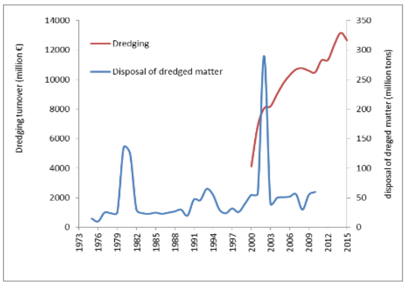
Figure 2.5: EU maritime sector indicators

A. Extraction of minerals



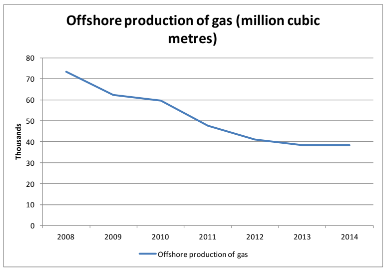
Source: ICES, 2017a

B. Dredging (EU) and disposal of dredged matter (global)



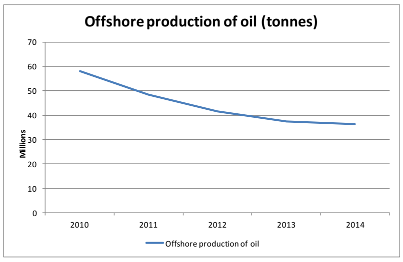
Source: EUDA, 2016; London Convention reporting 1975–2010,

C. Extraction of gas



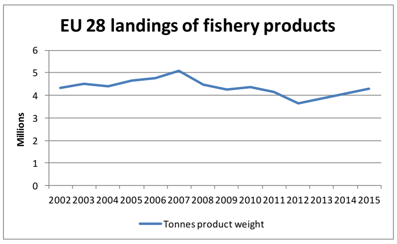
Source: COGEA et al., 2017e

D. Extraction of oil



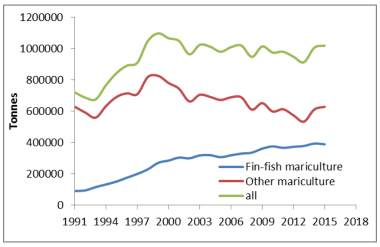
Source: COGEA et al.., 2017

E. Extraction of fish (fisheries)



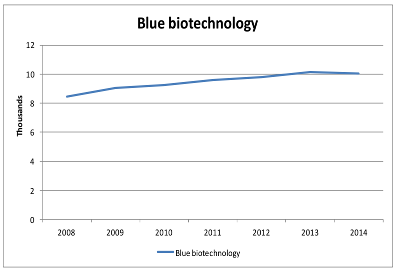
Source: Eurostat 2017f, data is EU15 for 2012 to 2015

F. Aquaculture in the EU



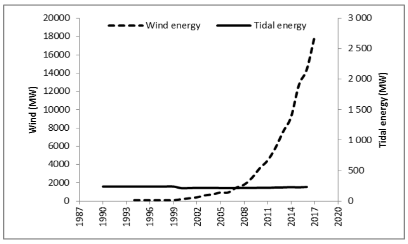
Source: FAO, 2017. Data for Bulgaria, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Malta, Netherlands, Portugal, Romania, Slovenia, Spain, Sweden, United Kingdom

G. Blue Biotechnology



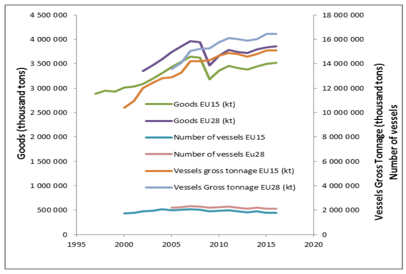
Source: COGEA et al., 2017

H. Renewable energy generation



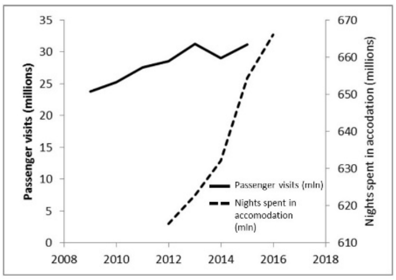
Source: EC, 2017b; WindEurope, 2018

I. Shipping



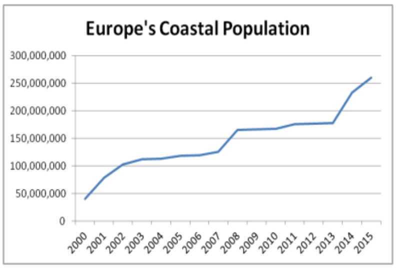
Source: http://ec.europa.eu/eurostat/data/database

J. Cruises and tourism



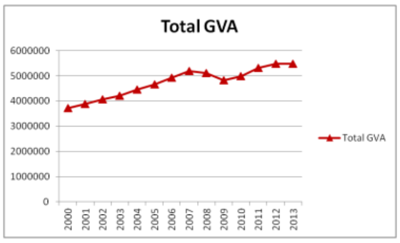
Source: CLIA 2015, 2016, Eurostat 2017c

K. European coastal population



Source: Eurostat 2017d

L. GVA of EU maritime activities



Source: Eurostat 2017

3 Pressures and their effects

KEY MESSAGES:

- The assessment shows spatial distributions of 14 pressures from human activities at sea and from land.
- Pressures are intensive in the shelf areas and along the coast, where multiple human activities overlap.
- Data gaps occur for all the pressures, especially in the southern marine regions, but despite that the report gives a robust overview of the pressures in Europe’s marine area.

This chapter presents assessment results of the pressures in Europe’s seas, caused by human activities at sea and on land. Fourteen pressure types, as defined by the MSFD Annex III were included in the analysis. Data and assessments from this chapter feed the analysis of combined effects, presented in Chapter 4. Due to data limitations, inputs of water (e.g. brine), organic matter and genetically modified species, or translocation of native species were not included in the analysis. MSFD pressure type’s definitions are often broad, therefore some pressures were split into separate pressures.

The assessment of pressures has required tapping into numerous European data sources such as the EEA, Eurostat, ICES, EU Joint Research Centre, RSCs, regional EU projects and EMODnet. All the pressures were assessed as spatial layers. For many pressures the data layers were prepared by identifying human activities causing a pressure, mapping the activity data and then aggregating that into a pressure proxy layer. Some layers like inputs of nutrients and introductions of non-indigenous species (NIS) were prepared on the basis of in-situ observations at sea. The data for analysis were collected from the period 2011–2016.

Europe’s sea areas are large; therefore, spatial layers were made in 10 km × 10 km grid cells, using the EEA reference grid. For some pressures the magnitudes were assessed (e.g. physical disturbance by trawling intensity), but in many others only occurrence was counted for the assessment period (e.g. NIS). The pressure distributions were further divided to coastal strip (nearest grid cells to the coastline), continental shelf (although it usually covers up to 300–400 m, here we have used a depth down to 1,000 m, to cover the effects of some fishing gear) and the offshore areas deeper than that. These help to distinguish the key areas where the pressures take place while together, they represent an overview of the human presence in our seas. All the pressure layers are described in Appendix A.

In this assessment, temporal changes in pressure intensity have been shown whenever evidence has been available. Specific focus has been given to human activities or pressures which have been estimated as particularly adverse. We also assessed the potential effects of pressures on the marine environment. ‘Effect’ is the *expected* outcome of the pressure for different species and habitats. It is not a measured impact and therefore the effects in this report are *potential effects*. In contrast, an impact is the *measured outcome* of the pressure for different species and habitats; this is observed in the state assessments of these features (Vaughan et al., 2019).

The potential combined effects on marine species and habitats were estimated using the method for assessment of cumulative effects, for the entire suite of pressures and a selected set of marine species groups and habitats by an index (Halpern et al. 2008, see Chapter 4). The cumulative effect assessment (CEA) builds on spatial layers of pressures and ecosystem components and an estimate of ecosystem sensitivity through an expert questionnaire. The questionnaire asked for estimates of sensitivity of each species group or habitat for a specific pressure. Even if expert elucidation cannot provide as specific guidance as measured observations, it allows for coherent and comparable sensitivity estimates over a range of features, many of which are not specifically monitored.

Methodology published in scientific literature requires an assessment of synergistic and antagonistic effects from different pressures. At the time of writing this report that was not feasible at the level of Europe's seas – that is the reason why we use the term 'combined effects' and not 'cumulative effects'.

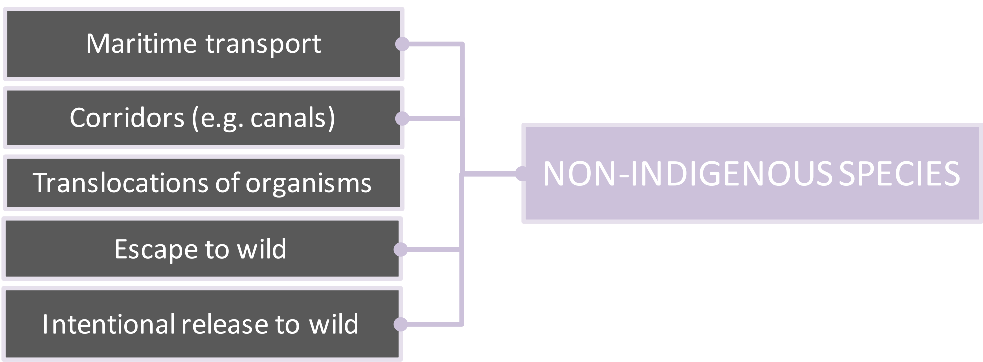
3.1 Non-indigenous species introduction

KEY MESSAGES:

- 1,555 NIS have been identified in Europe's seas in the period 1949–2019.
- 852 species have established viable populations; 81 of these species are invasive with the high potential of having negative impacts on biodiversity and therefore causing economic and social consequences.
- More than 50 % of Europe's coastal area is estimated to be impacted by invasive species (25 % in the NE Atlantic to 98 % in the Mediterranean and 100 % in the Black Sea).
- The observed rate of introductions has been getting slower in the past few years, but cumulative numbers of NIS are still increasing.

NIS are species that have been spread as a result of human activities to areas where they do not belong naturally (Figure 3.1). Main concern are invasive species that are defined as causing *"a significant negative impact on biodiversity as well as serious economic and social consequences"*. Biological invasion is an ongoing process globally and European Seas are no exception.

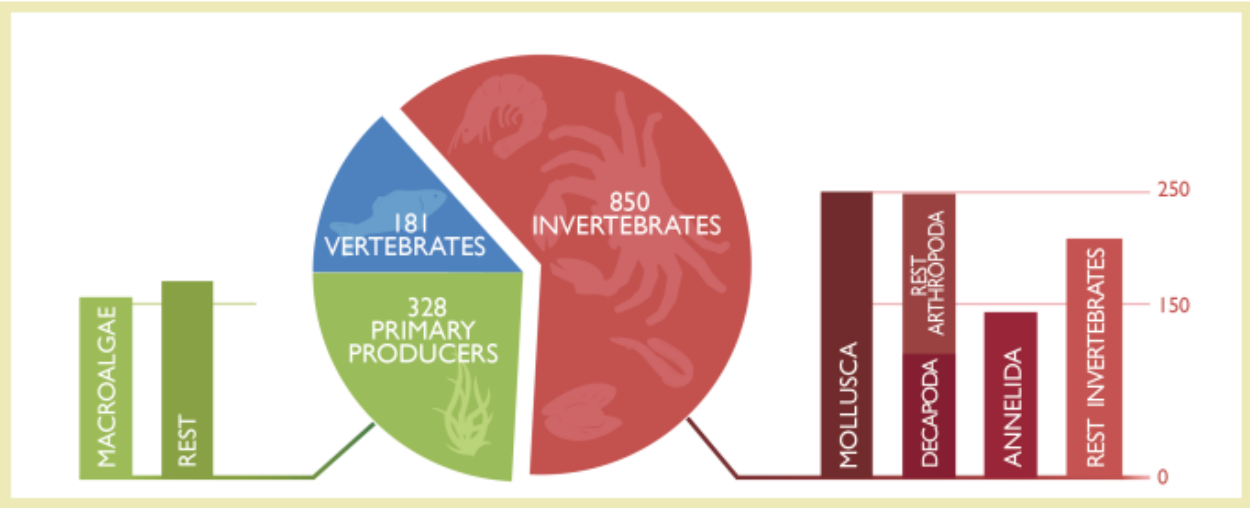
Figure 3.1: Activities causing introductions of marine non-indigenous species in European seas



Number of NIS in Europe's seas

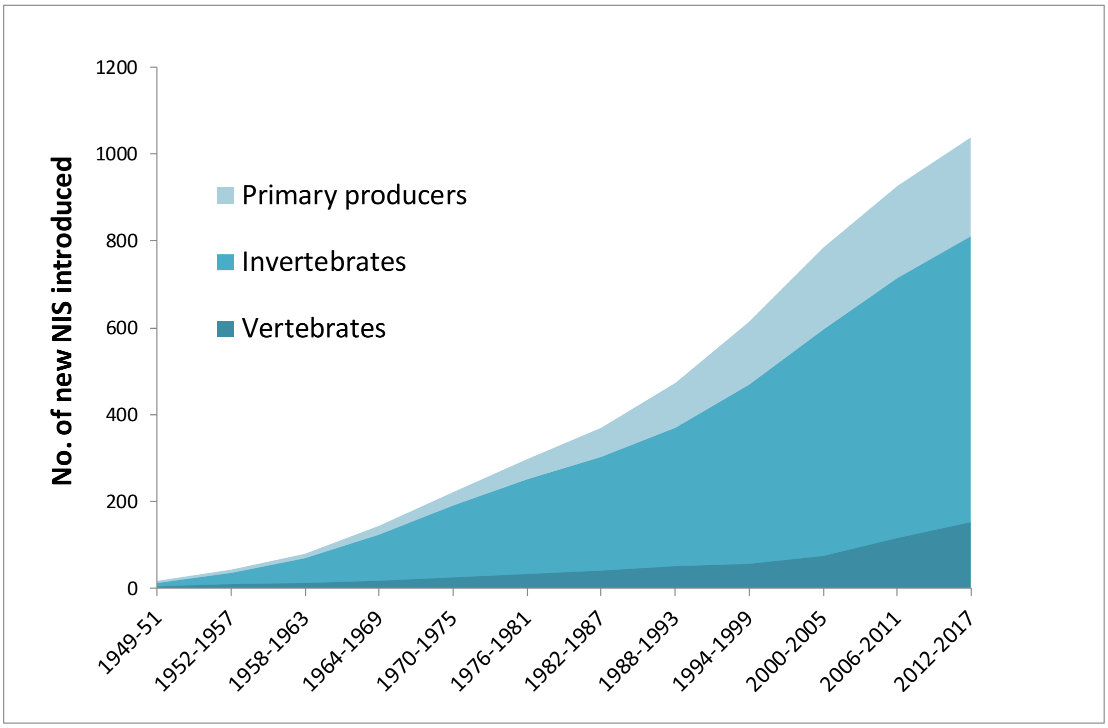
By June 2019, 1555 NIS have been recorded in European seas, of which 1,359 are true NIS and 255 species are classified as cryptogenic (origin unknown) or questionable (species complex or identity not confirmed) (Figure 3.2). These figures exclude the Macaronesian region. Based on our records, more than two thirds of the NIS (852 species) have established viable populations while the rest are either known from single records (371 species) or their establishment success has not been confirmed.

Figure 3.2: Classification of the non-indigenous species (850 invertebrate species constituting of 249 species of Mollusca, Arthropoda (247), Annelida (145), Cnidaria (60), Bryozoa (45), Ascidiacea (35), Platyhelminthes (20) and Echinodermata (13)). The data covers known introductions until June 2019.



Of the 1,359 NIS, > 80 % (1,125 species) have been introduced after 1949. At Pan-European level, the introductions – calculated as 6-year-means – have increased since the 2000s and culminated in the 2005–2011 period with 30 species per year (approximately one species every 1.7 weeks). In the most recent period 2012–2017 the introductions dropped to 19 species per year (1 new species every 2.7 weeks) (EEA, 2019f). Only 5 new NIS in Europe were observed in 2018 but this could be the result of a time lag between finding and reporting. The speed of new introductions is slower, but still significant if results from EEA indicator (2019f): 332 NIS species more were identified by June 2019 then they were by the end of 2017 (Figure 3.3).

Figure 3.3: Trends in introductions of marine non-indigenous species (vertebrates, invertebrates, primary producers) after 1949–2017 per 6-year periods in the whole of Europe and in the regional seas (EEA, 2019f)

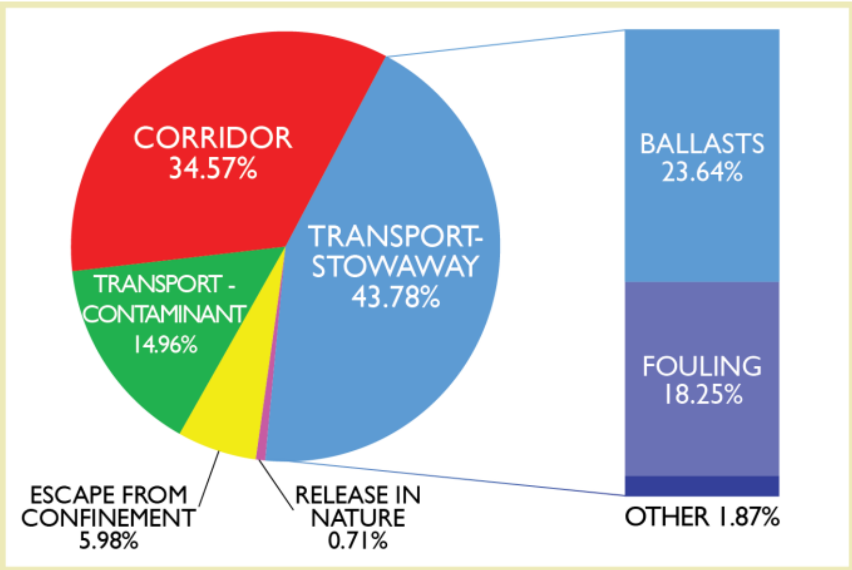


At national level, there are 14 EU countries where the number of marine introduced species via human activity in 2017 was reduced to zero (Lithuania, Finland, Poland, Sweden, Estonia, Latvia, United Kingdom, Ireland, Denmark, Belgium, Norway, Netherlands, Spain, and Germany). On the other hand, NIS already introduced in many countries have significantly expanded their distribution range, spreading also from non-EU areas.

Major pathways of introduction of non-indigenous species

The transfer of NIS in European Seas since 1950 with vessels (ballast water, tank sediments, and hull fouling, other vectors) is the greatest pathway to marine regions (43.8 %) (EEA, 2019g). It exceeds the importance of other pathways followed by unintentional introductions via marine and inland corridors (34.5 %), unintentional movement of live organisms as contaminants (14.9 %), escapes from aquaria, aquaculture and mariculture (6.0 %), while intentional releases in nature account for just 0.7 % (Figure 3.4).

Figure 3.4: Mode of introduction of Non-Indigenous Species in European Seas after 1950.



A general decrease is evident in all pathways for all seas (Fig.3.5, EEA, 2019g). Among pathways “Escape from confinement”, and in particular accidental or irresponsible ‘Release’ of live organisms from aquaria deserves mentioning. Aquaria and trade in aquarium and ornamental species are emerging as an important source for species likely to invade aquatic habitats (Padilla and Williams, 2004). The phenomenon is particularly worrying in the Mediterranean (Spain, Italy, Malta, Greece), where more than 20 fish species among those imported and kept in domestic aquaria (Figure 3.6) have been detected in the wild (Zenetos et al., 2016).

Enlargement of the Suez Canal was expected to cause increasing rate of introductions, but the study in 2017 indicated the opposite, a rather decreasing rate of introductions (Zenetos, 2017). Results showed that 12 new NIS were detected in the period August 2015 (date of the last Suez Canal enlargement) to August 2017 (EEA, 2019h).

Figure 3.5: The role of human activities introducing new non-indigenous species into Europe's seas as 6-year periods between 1950–2017. The classification of pathways follows the CBD (2014) scheme. Note the different scales in vertical axes (EEA, 2019 g).

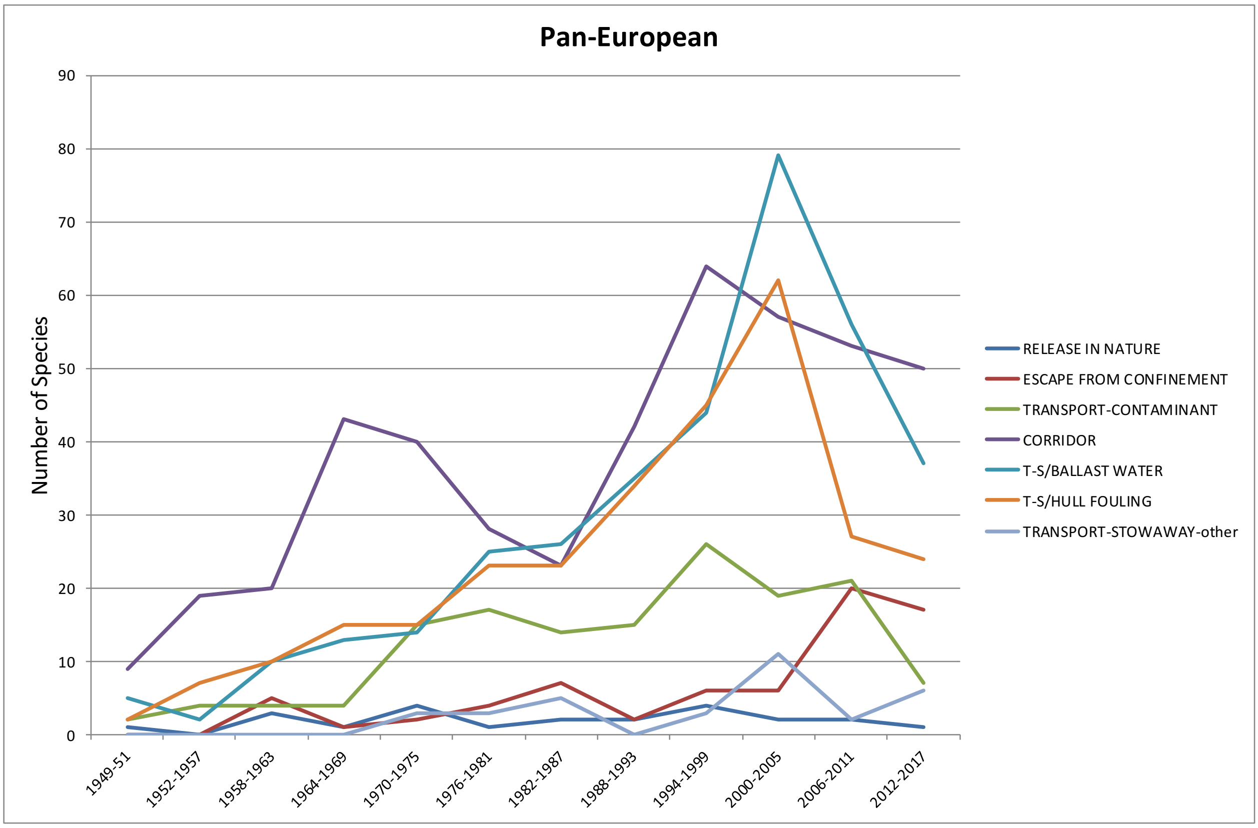


Figure 3.6: Invasive species and released aquarium species. Upper: the round goby (*Neogobius melanostomus*) is spreading in Finland (photo credit Maiju Lehtiniemi). Below: the yellowtail tang (*Zebrasoma xanthurum*) is a released aquarium species, observed at Tavolara Island, Sardinia (photo credit Luana Magnani)

Most of the marine NIS in Europe originate from the Western Indo-Pacific. This result is similar for all main taxonomic groups, with the exception of macroalgae which originate mostly from the NW Pacific. The temperate Northern Pacific and the central Indo-Pacific also constitute important sources of European NIS (Tsiamis et al., 2019, based on EASIN data).

Box 1 Cooperation in ballast water control: A case study in the Adriatic Sea

A Ballast Water Management Plan and Strategy, (BALMAS) was developed aiming at establishing a common cross-border system, which will link all researchers, experts and responsible national authorities from Adriatic countries in order to avoid unwanted risks to the environment from the transfer of harmful aquatic organisms and pathogens. A Decision Support System (DSS) that includes ballast water management (BWM) control measures for compliance with BWM Convention and Paris memorandum of understanding was developed to support implementation of the BWM convention in the Adriatic, as well as to upgrade compliance monitoring standards for the Adriatic. The model was developed and tested integrating the measures agreed. This is meant to increase the control of BWM measures implemented by vessels calling to the Adriatic ports, though the implementation may be gradual.

Adverse effects of marine NIS

Cumulative negative impacts of marine NIS species were assessed using the Cumulative IMPact of ALien species (CIMPAL) index, developed by Katsanevakis et al. (2016) (see Appendix E). The index follows a conservative additive model for calculating the cumulative negative impacts of invasive alien species (IAS), based on magnitude of impact and the related strength of evidence following an uncertainty-averse strategy (see Annex E). The impacts score are categorized into 5 classes: ranging from no or negligible effects to irreversible in the short term (< 1 decade). Impacts, considered in classification entail:

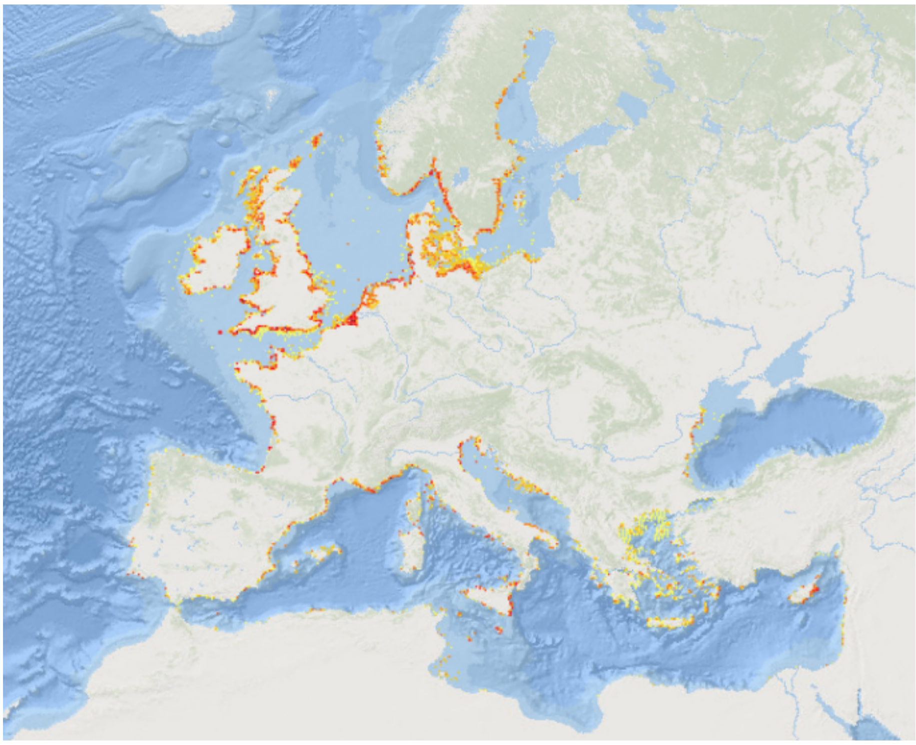
- Reduction in individual fitness due to competition or predation or parasitism or toxicity or bio-fouling or herbivory;
- Impact on ecosystem processes and ecosystem functioning; impacts on keystone species or species of high conservation value;
- causes changes in chemical, physical or structural habitat characteristics;
- Ecological engineering;
- Change in community composition.

In the CIMPAL study, 81 IAS were estimated as invasive alien species (IAS) at pan-European level, i.e. they prosper in the new area and widen their distribution range, often at the cost of the native species (Appendix E). Of these IAS, the highest numbers are found from the eastern Mediterranean coast and the southern North Sea coast (> 35 species), whereas less than 5 species are found from the coasts of Iberian peninsula, Bay of Biscay and Ireland as well as the Baltic Sea, western Mediterranean and NE Atlantic (excl. the Greater North Sea).

A review of European marine IAS showed that negative impacts dominated over positive ones (Katsanevakis et al., 2014), even though the difference was not wide. For several species the impacts have not been documented. The review also showed that marine IAS were typically impacting several species, ecosystem functions or modifying natural habitats.

Cumulative impacts of IAS (CIMPAL; Katsanevakis et al., 2016) were estimated on the basis of the distributions of invasive species and ecosystems, and both the reported magnitude of ecological impacts and the strength of such evidence. In this study, mapping the impact of alien species on marine ecosystems at pan-European scale by employing the CIMPAL index revealed a strong spatial heterogeneity across EU Seas (Figure 3.7). The negative impacts were largely restricted to coastal areas, with offshore areas presenting mostly no evidence of impact (score = 0 in most cells).

Figure 3.7: European seas cumulative impact score (CIMPAL) of 81 invasive alien species to marine and coastal habitats, based on the uncertainty-averse strategy. See Appendix A for the data layer description



Even if only a fraction of all NIS, IAS cover currently 53 % of Europe's coastal strip, while they live only in 11 % of the shelf area and 4 % of the waters beyond the shelf. The Black Sea area is entirely covered by IAS, and in the Mediterranean their distribution covers 98 % of the coastal strip and 41 % of the narrow shelf area. In the Baltic Sea and the NE Atlantic, these figures are 33 % and 25 % (coastal strip) and 9 % and 1 % (shelf) (Figure 3.7).

What can we do?

The EU IAS Regulation states that Member States must carry out a comprehensive analysis and prioritisation of the pathways of unintentional introduction and spread of the species on the EU list of concern.

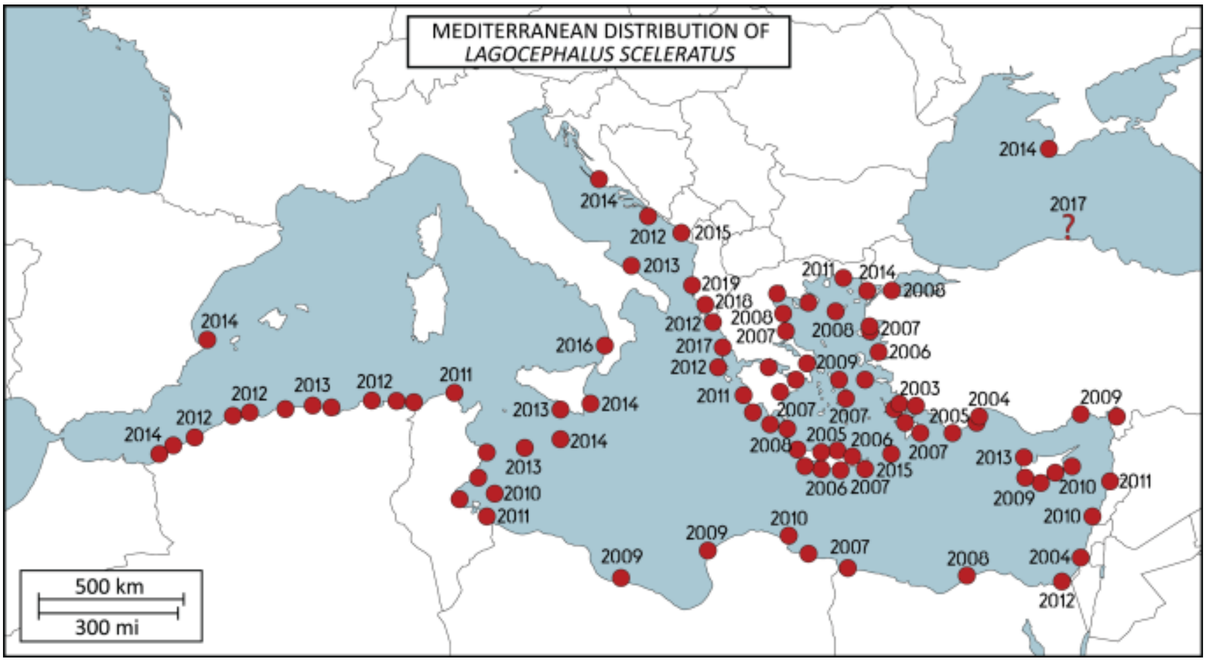
High-ranking species either absent in European seas or restricted to a few isolated small populations include 24 marine species (8 of very high risk, 7 of high risk, 9 of medium risk). Among the very high-risk species the Devil firefish/Lion fish (*Pterois miles*) ranked first, followed by the Northern brown shrimp (*Penaeus aztecus*), Striped eel catfish (*Plotosus lineatus*) and American Lobster (*Homarus americanus*) (Roy et al., 2015) (Figure 3.8).

Presently a venomous fish species *Plotosus lineatus* of Indo-Pacific origin has been risk assessed (Figure 3.8). *Plotosus lineatus* is not yet proliferating within marine subregions of the EU, but has established populations in neighbouring countries (Egypt, Israel, Lebanon, Syria, and Turkey) and will very likely enter the EU region by natural dispersal. Considering its availability through the aquarium trade and its popularity in large public aquaria, the likelihood of entry through aquaria related pathways is deemed as high. *Plotosus lineatus* is the first marine species to be included in the list of IAS Species of Union concern (June 2019; Figure 3.8).

The next risk assessed species at pan-European level is the Silver-cheeked toadfish (*Lagocephalus sceleratus*) which is widely distributed in the Mediterranean (Figure 3.9). Today it is considered an invasive species in Cyprus and Greece, as it is known to damage both the fishing gear and the catch of the fishermen with its powerful jaws and it contains a powerful neurotoxin which can cause serious poisoning, even death, if consumed.

Figure 3.8: Top four species likely to invade European seas

Figure 3.9: Distribution of the toxic Silver-cheeked toadfish *Lagocehalus sceleratus* in the Mediterranean



Biofouling: need for action

Biofouling is the accumulation of aquatic organisms such as micro-organisms, plants, and animals on surfaces and structures immersed in or exposed to the aquatic environment (IMO, 2011). The recent increase in the merchant fleet (UNCTAD, 2015) and recreational boating has transformed vessels into significant "vectors of change" in marine ecosystems. Vessel biofouling causes also economic costs to vessel management.

Lack of an international regulatory framework addressing the prevention of fouling-mediated transfer of marine NIS has already prompted the governments of New Zealand and the State of California, USA, to implement biofouling regulations within their jurisdictions, and Australia is considering doing the same. There is, therefore, a need for the development of a comprehensive international agreement to address this gap, incorporating technical regulations/guidelines to provide Flag administrations and Port State Authorities with guidance to minimize the risk of dispersal of harmful organisms by befouled vessels (Berkey & BenDor, 2012).

Box 2 Legislation and international agreements on IAS

GLOBALLY – Convention on Biodiversity (CBD), Aichi Target 9, "By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment".

The International Maritime Organization (IMO) Ballast Water Management Convention (BWMC) which entered into force on 8 September 2017 requires all ships to implement a ballast water management plan.

PAN-EUROPEAN – Aichi Target 9 is reflected in Target 5 of the EU Biodiversity Strategy, where "By 2020, invasive alien species are identified, priority species controlled or eradicated, and pathways managed to prevent new invasive species from disrupting European biodiversity".

The EU MSFD includes NIS as one of the 11 descriptors to assess Good Environmental Status and it aims at ensuring that non-indigenous species are at levels that do not adversely alter the eco-systems.

The EU Regulation 1143/2014 on Invasive Alien Species sets obligations for European countries in respect to IAS.

REGIONALLY – HELCOM, amongst numerous programs, has actualized the Baltic Sea Action Plan (BSAP). OSPAR aims to protect, conserve and restore the ecosystems and the biological diversity of the maritime area which are affected by human activities, such as NIS. The Barcelona Convention in the Mediterranean Sea has set an "Action plan concerning species introductions and invasive species".

3.2 Commercial exploitation of fish and shellfish stocks

KEY MESSAGES:

55.2 % of the assessed commercially exploited fish and shellfish stocks across Europe's seas meet at least one out of two primary criteria defining the MSFD's 'good environmental status' objective for commercial fish and shellfish species.

At least 37 % of Europe's seas shelf area is fished using towed gear. This excludes gillnets, traps and other fishing gear also used by the EU fleet.

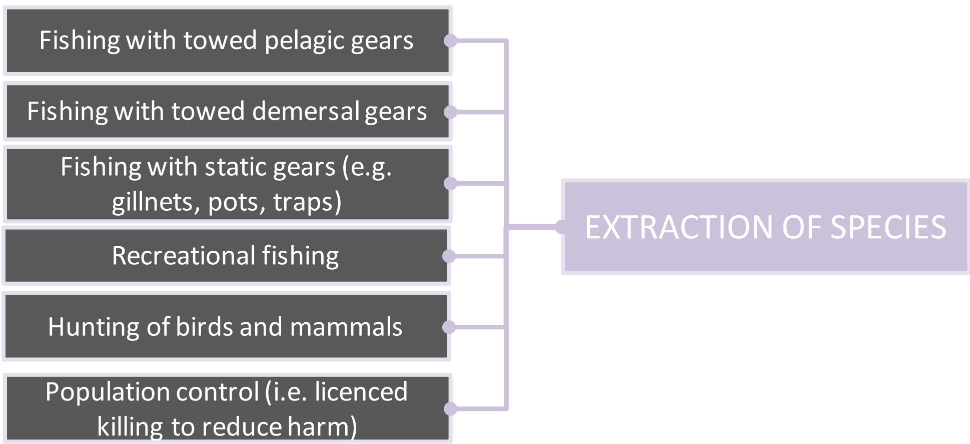
In the Mediterranean Sea and the Black Sea, only 6 % and 14 % of the assessed commercial stocks meet either the target of having a fishing mortality rate or a reproductive capacity being compatible with delivering biomass levels above those capable of producing Maximum Sustainable Yield (MSY), respectively.

Decreased fishing pressure and better fisheries management in the North-East Atlantic Ocean and the Baltic Sea, have led to signs of recovery in the reproductive capacity of several commercially exploited fish and shellfish stocks.

The 2020 objective of the Marine Strategy Framework Directive, which is partly shared by the Common Fisheries Policy, requiring that all commercial stocks across all EU marine regions are exploited at MSY is unlikely to be met.

Fisheries cover large marine areas and are considered as one of the most impacting human activities in the marine environment (Micheli et al., 2013; FAO, 2016; OSPAR, 2017; HELCOM, 2018a). The commercial exploitation of fish and shellfish stocks is a well-studied and well-understood pressure which not only impacts the target species, but also other non-target species because of by-catch; some to the extent of high concern (Figure 3.10; Lewison et al., 2014). The use of certain fishing gear and methods also causes physical loss and disturbance to seabed habitats (see Section 3.4).

Figure 3.10: Activities for extraction of species in European seas



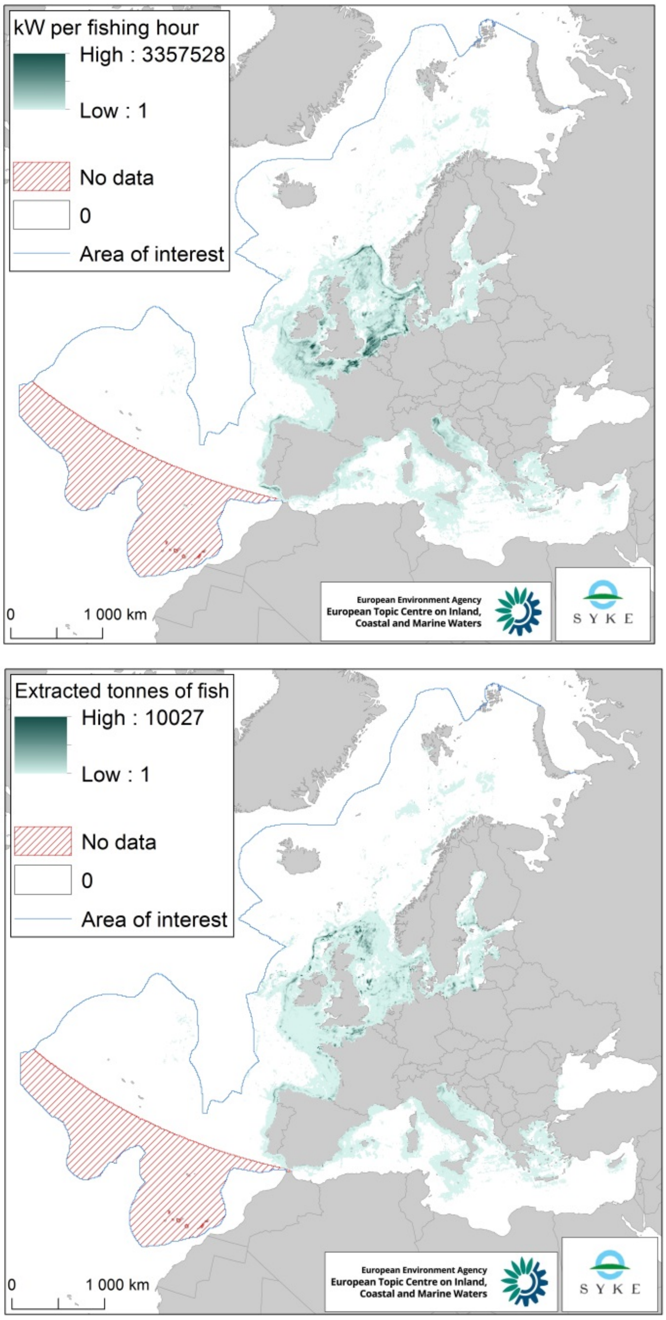
Fishing is practiced in at least 37 % of the EU continental shelf by the EU fleet with towed gear (Figure 3.10 and Figure 3.11). In the marine regions, this assessment estimated that towed gear is used in 53 % of the area in the Baltic Sea, 26 % in the Mediterranean, 14 % in the NE Atlantic and 2 % in the Black Sea (EU-fleet). Fishing is more intensive in the shelf waters than other zones: 4 % (Black Sea), 34 % (NE Atlantic), 49 % (Mediterranean) and 68 % (Baltic). The small-scale and recreational fisheries and all the fisheries with gillnets, pots and traps are not included in these figures. Especially, in the southern regions the role of small-scale fisheries is strong and therefore the areal impact is actually much higher.

Changes in fishing effort

The EU fishing fleet had 84,420 vessels (> 12 m in length) in 2015 with a combined gross tonnage (GT) of 1.6 million tonnes and engine power of 6.4 million kW (STECF, 2017). The EU-28 fishing fleet has decreased steadily (2 % in year) between 1990–2015 in gross tonnage, engine power and number of vessels. E.g. the number of vessels decreased by near 11 % between 2000 (EU-15) and 2015 (EU-28) (Eurostat, 2017g). In many Member States the decline has been much steeper. This change is more visible in the northern regions.

In the Mediterranean and Black Sea, 84 % of vessels are < 12 m in length, there are altogether 86,500 vessels in the two regions and near 13 % of them operate in the Black Sea (non-EU countries included; FAO, 2018b). In the EU-28, the share of small-scale fisheries is 74 % of the fleet and only 10 % of these uses active gear (Stobberup et al., 2017).

Figure 3.11: Fishing effort in the EU marine area



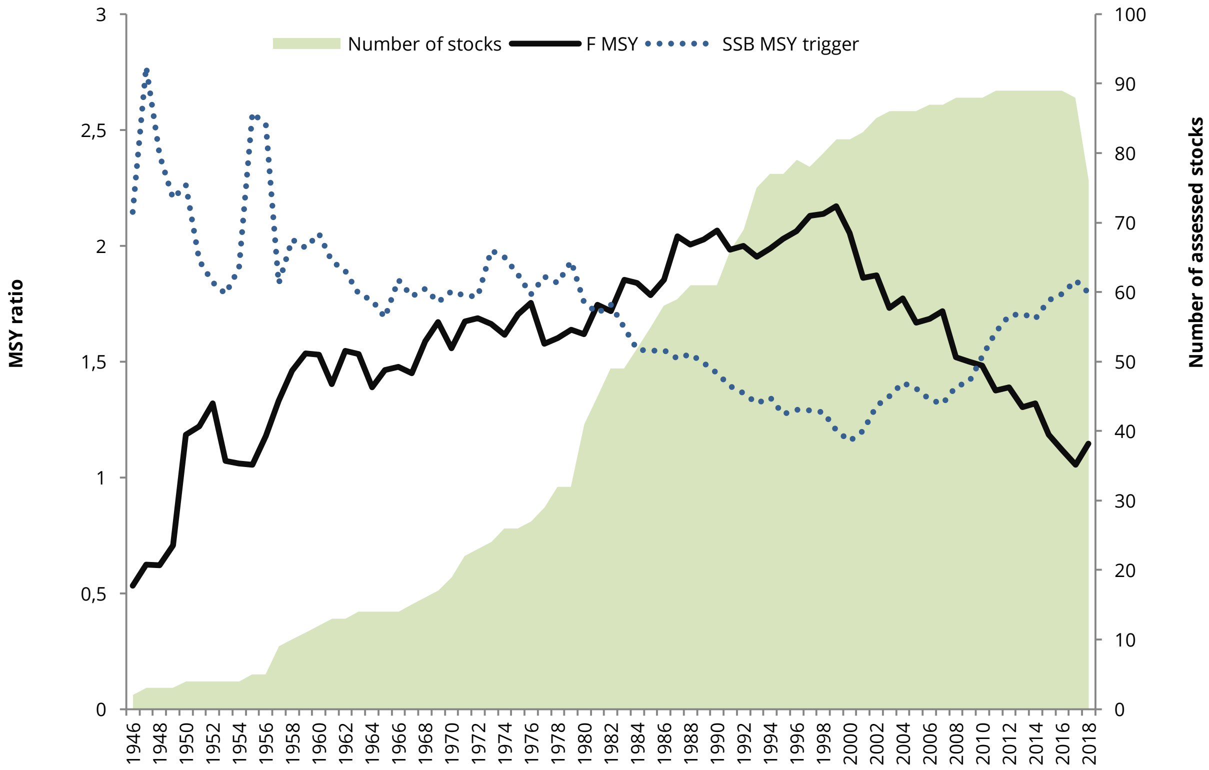
Notes: See Appendix A for the data layer description

Changes in fishing mortality and fish and shellfish catches

Fishing mortality, i.e. fishing pressure (F), is a way to estimate the impact of the exploitation of commercial fish and shellfish stocks because it affects the stocks reproductive capacity (i.e. spawning stock biomass, SSB). Sustainable fishing requires, *inter alia*, that the fishing mortality rate and reproductive capacity of commercial stocks are compatible with delivering biomass levels above those capable of producing MSY**.**

Fishing mortality increased in the NE Atlantic Ocean and Baltic Sea from approximately sustainable levels in the 1950s until the late 1990s when it was more than two times over the sustainable level (Figure 3.12; EEA, 2019c). After this, the mortality had a steep decline towards sustainable levels, although, on average, these have not been achieved yet. For example, fisheries in the oceanic NE Atlantic (i.e. Mid-Atlantic Ridge and oceanic seamounts and the Azores archipelago) peaked in 1980–90s but have significantly declined after 2010, *inter alia*, due to management measures (ICES, 2018). From the early 2000s onward, the first signs of recovery of the reproductive capacity of the commercial fish and shellfish stock exploited in that region have been visible as the result of a decrease in fishing mortality.

Figure 3.12: Changes in fishing mortality (F, black line) and reproductive capacity (SSB, dotted line) in the Northeast Atlantic and the Baltic Sea (mean of all stocks)

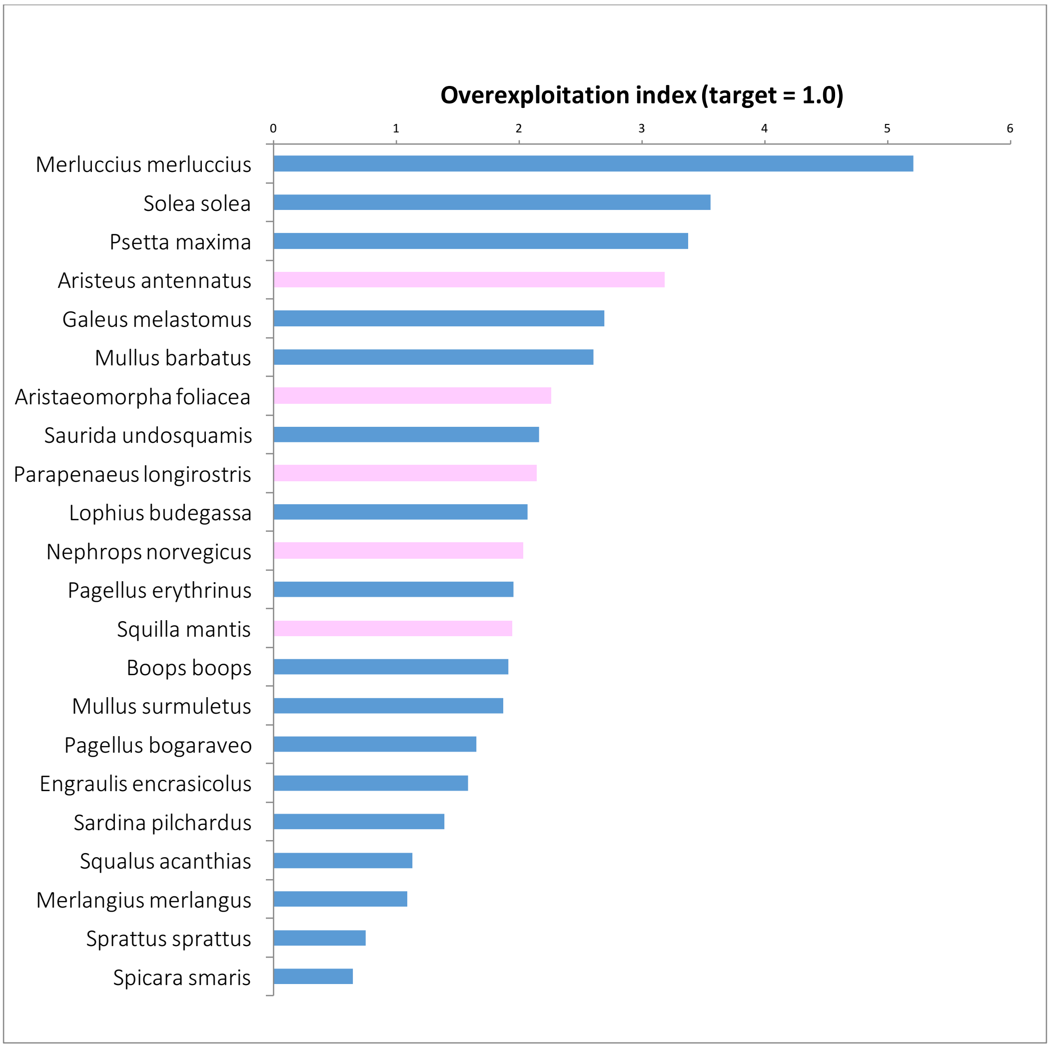


Notes: Both F and SSB parameters have been related to their stock-specific thresholds (= 1.0). Fishing morality < 1.0 indicates sustainable fishing and reproductive capacity > 1.0 indicates a healthy stock. The number of assessed stocks is shown as the greyish area. MSY: maximum sustainable yield.

Source: EEA, 2019c.

In the Mediterranean Sea and the Black Sea, fishing mortality has been far too high for many years and most commercial fish and shellfish stocks are overexploited (FAO, 2018b; EEA, 2019c). Overexploitation for many of these stocks is 3–5 times over the sustainable levels (Figure 3.13) and even 12 times for a few local stocks (FAO, 2018b). Six of the top ten most overexploited species live in deeper waters of the continental slope.

Figure 3.13: Overexploitation of the major commercial fish (blue) and crustacean (purple) stocks in the Mediterranean and the Black Sea



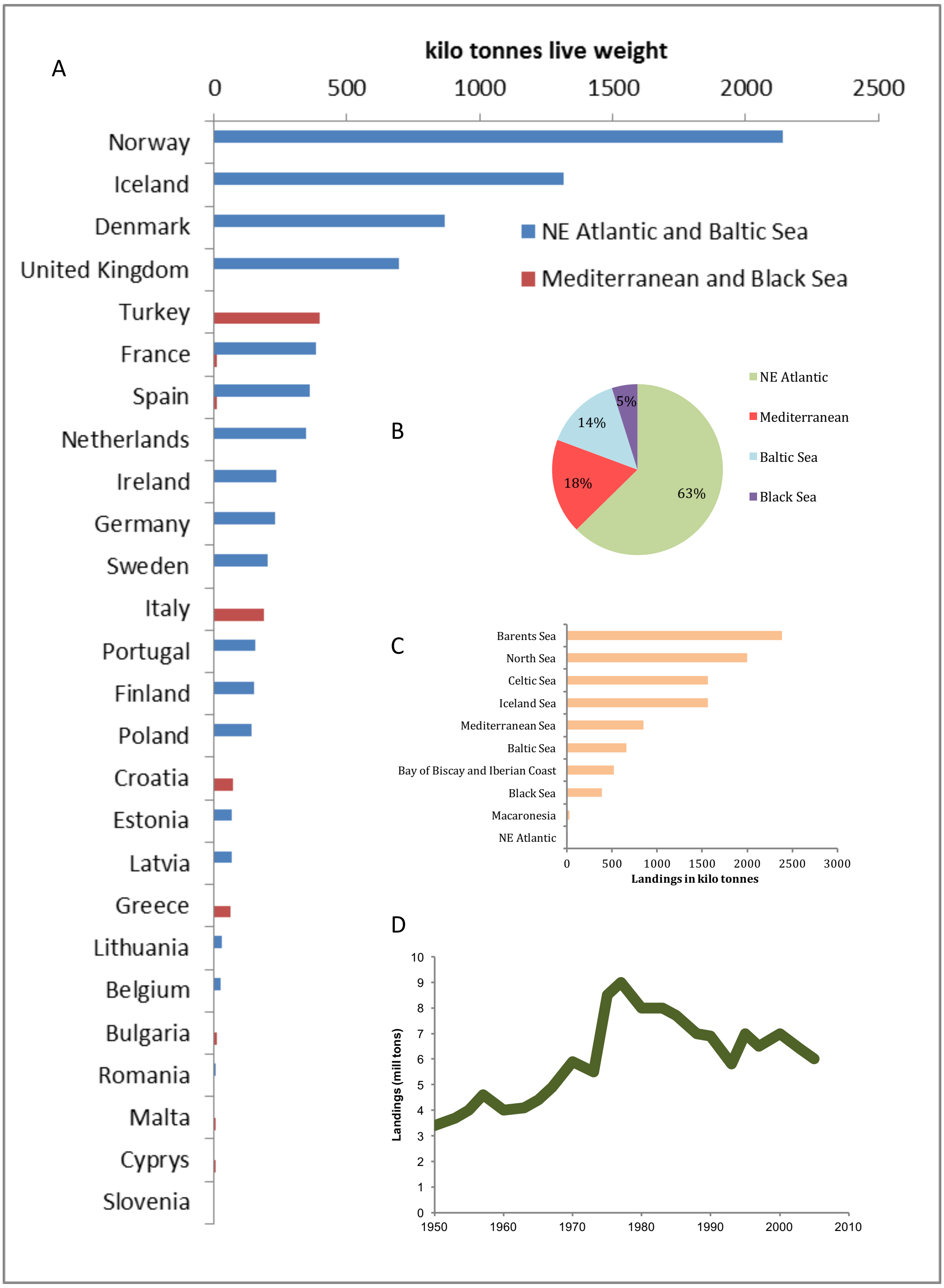
Notes: The index score 1.0 indicates sustainable level. Source: Redrawn from FAO, 2016.

The magnitude of commercial stock exploitation is estimated by total catches in the EU Member States and by total landings (catches minus by-catch) per fishery region. However, in well-managed fisheries, catches/landings do not indicate the overall effects of commercial fishing and, therefore, the results need to be interpreted carefully. European catches of commercial fish and shellfish stocks peaked in 1980s and have declined since, even down 21 % since 2000 (Figure 3.14; Eurostat, 2017f). In 2015, most of the EU-28 catches were made in the NE Atlantic marine region (63 %; Figure 3.14), where especially demersal stocks are fished for intensively (OSPAR, 2017).

The live weight of catches for the EU-28 was 5.1 million tonnes in 2015 (Eurostat, 2017f). In addition, Norway, Iceland and Turkey fished 2.1, 1.3 and 0.4 million tonnes respectively (Figure 3.14).

In the NE Atlantic Ocean and the Baltic Sea combined, more than half (58 %) of the 2015 catch came from five species, where the Atlantic herring is by far the most caught species representing close to one fifth of the total EU-28 catch (Eurostat, 2017). It was followed by Atlantic mackerel and European sprat (both 13 %), then blue whiting and sandeels (both 6 %). In the Baltic Sea particularly, herring, sprat and cod were the most important species landed (STECF, 2017).

Figure 3.14: (A) Total catches in European countries in 2015, (B) Comparison of total landings across EU marine regions in 2014, (C) Total landings per fisheries areas in 2014, and (D) Development of the total fish landings in Europe



Sources: A – Eurostat 2016; B – EEA, 2019c; C – EEA, 2019c; FAO, 2018b; and D – EU DEDUCE project (http://www.vliz.be/projects/deduce/index.html).

In the Mediterranean and Black Seas, the catches peaked in late 1980s' – early 1990s and declined thereafter (FAO, 2018b; Eurostat, 2017). In these marine regions, fisheries target herring, sardines and anchovies, which account for 49% of the landings (FAO, 2018b).

Status of commercially exploited fish and shellfish stocks

The sustainable exploitation of fish and shellfish (and other) stocks is part of a 2020 Aichi target under the Convention on Biological Diversity and also the objective of several pieces of EU policy. To be sustainable, the fishing mortality rate and reproductive capacity of all commercially exploited stocks across all EU marine regions need to be compatible with having population biomass levels above those capable of producing MSY by 2020. This is required as part of fulfilling the MSFD's GES objective for Descriptor 3 on 'Commercially exploited fish and shellfish' (EC, 2017a).

Currently, 89.5 % of commercially exploited fish and shellfish stocks cannot be assessed at the EU level in terms of whether they meet both these two primary criteria defining GES. Then, 100 % of commercially exploited stocks cannot be assessed at the EU level in terms of also meeting the third primary criteria, on the age and size structure of the stocks populations, rounding up the GES definition (Table 3.1) (EEA, 2019c).

The proportion of assessed commercially exploited fish and shellfish stocks varies a lot across, and within, EU marine regions. This depends on the total number of stocks that are typically part of each region's landings, which is highest in the NE Atlantic Ocean and lowest in the Black Sea. It also depends on how many can be assessed in terms of meeting at least one of the (39.3 % of the stocks across the whole EU) or both (10.5 % of the stocks across the whole EU) primary GES criteria requiring that their fishing mortality and/or reproductive capacity is MSY-compliant (Table 3.1) (EEA, 2019c).

55.2% of the assessed commercially exploited fish and shellfish stocks across Europe's seas meet at least one out of two primary criteria defining the MSFD's 'good environmental status' objective for commercial fish and shellfish species. 82.3 % and 62.5 % of the assessed stocks in the NE Atlantic and the Baltic Sea meet at least one of these two GES primary criteria, respectively in 2017. In contrast, only 6.1 % and 14.3 % of the assessed stocks in the Mediterranean Sea and the Black Sea do so, respectively in 2016 (Table 3.1) (EEA, 2019c). In the Mediterranean Sea, the number of assessed stocks is biased towards the Western Mediterranean and the Adriatic seas (FAO, 2018b; Froese et al., 2018). Beyond the decline in the total fish population (-34 %; especially the larger fish), important fisheries' impacts in the Mediterranean Sea over the last 50 years include the decline in the proportion of marine mammals (-41 %) (Piroddi et al., 2017). This decline is most dramatic in the Western Mediterranean Sea and the Adriatic Sea (-50 %).

The fact that stock assessments cover only part of all the commercially exploited fish and shellfish stocks brings additional uncertainty into the assessment here. Nevertheless, important signs of improvement are being observed in the NE Atlantic Ocean and Baltic Sea. Since the early 2000s, better management of commercial fish and shellfish stocks has contributed to a clear decrease in fishing pressure in these two marine regions (e.g. Zimmermann & Werner, 2019) (Figure 3.12). This is evidenced by emerging signs of recovery in the reproductive capacity of several of these stocks (Figure 3.12). Despite these efforts and signs, however, the MSFD GES objective for Descriptor 3, which is partly shared by the Common Fisheries Policy (EU, 2013) and also a target under the EU Biodiversity Strategy to 2020, is unlikely to be met across Europe's seas (Table 3.1) (EEA, 2019c).

How are the large fish doing?

Several independent methods have shown that the bottom-trawling fishery has reduced the stocks of large fish species by 90–96 % (Thurstan et al., 2010).

The Scombridae family of the mackerels, tunas, and bonitos, includes many of the most important and familiar food fishes. The largest ones were heavily overfished some decades ago. According to the 2016 assessment, the Atlantic albacore (*Thunnus alalunga*) and the yellowfin tuna (*T. albacares*) currently both meet the MSY targets (ICCAT, 2018). The bluefin tuna (*T. thynnus*) and the Mediterranean albacore stocks are likely fished sustainably but there are uncertainties related to the current state (ICCAT, 2018). The skipjack tuna (*Katsuwonus pelamis*), the bigeye tuna (*T. obesus*), two of the three horse mackerel stocks

(*Trachurus trachurus*) and the Atlantic mackerel stock (*Scomber scombrus*) are fished over the MSY targets (ICES, 2017b; ICCAT, 2018). Stock status of many of the smaller tunas are not assessed, except for the plain bonito (*Orcynopsis unicolor*; Vulnerable), the IUCN has classified them as 'least concern' (Nieto et al., 2015).

The European red list of marine fish classified 32–53 % of the sharks, rays and skates (i.e. chondrichthyans) to be threatened, 12 % critically endangered facing a high risk of extinction (Nieto et al., 2015). In NE Atlantic, ~ 35 % of chondrichthyan species were threatened, whereas in the Mediterranean Sea this was 57 %. An Atlantic stock assessment of three species of sharks, showed that the stocks of the blue shark (*Prionace glauca*), the porbeagle (*Lamna nasus)* and shortfin mako shark (*Isurus oxyrinchus*) are low due to past overfishing and it may take 15–34 years to recover (ICCAT, 2018). The fishing or retaining onboard of some shark species such as porbeagle have been forbidden in the EU since 2015 (Council, 2015).

Table 3.1 Environmental status of commercially exploited fish and shellfish stocks in relation to meeting two of the primary criteria defining the Marine Strategy Framework Directive's (MSFD) 'good environmental status' (GES) objective for Descriptor 3 on 'Commercially exploited fish and shellfish'

Stocks in relation to meeting two of the primary criteria defining the MSFD GES objective: Achieving (1) a fishing mortality and (2) a reproductive capacity compatible with having population biomass levels above those capable of producing Maximum Sustainable Yield	**NEAO**	**Baltic Sea**	**Black Sea**	**Mediterranean Sea**	**EU**
% of stocks for which it is possible to assess whether **both** these two GES primary criteria are met out of all exploited stocks	16.0	5.0	0	0	**10.5**
% of stocks for which it is possible to assess whether **at least one** of these two GES primary criteria are met out of all exploited stocks	36.4	40.0	77.8	41.8	**39.3**
% of assessed stocks meeting **both** these two GES primary criteria	44.1	12.5	0	0	**26.7**
% of assessed stocks meeting **either** of these two GES primary criteria	38.2	50.0	14.3	6.1	**28.5**
% of assessed stocks meetings **at least one** of these two GES primary criteria	82.3	62.5	14.3	6.1	**55.2**
% of assessed stocks **not** meeting **any** of these two GES primary criteria	17.7	37.5	85.7	93.9	**44.8**

Notes:

- The MSFD includes a third primary criterion to determine GES in relation to Descriptor 3 (i.e. on the age and size structure of the populations of fish/shellfish, cf. (EC, 2017a)) but, at present, there is no agreed EU-level method to assess it, hence it is not included here.
- The first two rows are based on the total number of commercially exploited fish/shellfish stocks landed across Europe's seas (295 stocks). Out of these, some stocks can be assessed using any of the above-mentioned two GES primary criteria for Descriptor 3 (116 stocks), others by different standards (52 stocks), and others are not assessed at all (127 stocks).
- The last four rows are based on the number of commercially exploited fish/shellfish stocks for which one and/or two of the primary criteria used to determine GES can be assessed (116 stocks).
- NEAO = North-East Atlantic Ocean
- Data gaps remains for many stocks.
- For more detail and full methodology, please refer to the EEA CSI032 indicator (EEA, 2019c).

Source: EEA (2019j)

Deep-sea fisheries and its effects

After technological advances and the need to find less exploited target species, deep-sea fisheries – at depths greater than 200–500 m – have become economically important in recent decades. The species captured are often characterized by longevity, low fecundity and slow growth, making them vulnerable to overfishing. As a result, most deep-sea stocks have undergone rapid and substantial declines, but a few stocks are fished sustainably (e.g. Victorero et al., 2018).

The share of deep-sea catches is very small (< 1 %) compared to other fisheries, but its local share on seamounts, ridges and slopes may be significant where even 83 % of benthic biomass such as corals, sponges and echinoderms has been depleted by subsequent trawl sweeps (Gage et al., 2005; Ramirez-Llodra et al., 2008; Benn et al., 2010; Clark et al., 2016). The greatest impacts are exerted by bottom trawls (especially hydraulic dredges if used in the area) and to a lesser extent by bottom long-lines (Clark et al., 2016), both typical types of gear for this environment. Of the deep-sea species, 35 % are currently red-listed (Nieto et al., 2015; Table 3.2).

The deep-sea ecosystems are slow in recovery. Comparisons between non-trawled and trawled sea-mounts showed that no signs of recovery were found after 5–10 years from the last trawling (Williams et al., 2010).

Table 3.2 Red-listed deep-sea fish and shellfish in the European red list of marine fish (Nieto et al., 2015). The list includes only the deep-sea fishery target species listed by the FAO.

Deep sea trawl fishery	
Roundnose grenadier (*Coryphaenoides rupestris*)	EN
Baird's smoothhead (Sebastes mentella)	EN
Leafscale gulper shark (Centrophorus squamosus)	EN
Portuguese dogfish (*Centroscymnus coelolepis*)	EN
Orange roughy (*Hoplostethus atlanticus*)	VU
Blue ling (*Molva dypterygia*)	VU
Alfonsino (*Beryx decadactylus*)	NT
Deep sea long lines	
Deep-sea sharks	*
Golden redfish (*Sebastes norvegicus*)	VU
Greenland halibut (*Reinhardtius hippoglossoides*)	NT
Atlantic wreckfish (*Polyprion americanus*)	NT
Gillnet fisheries	
Deep-sea sharks	*
Other fisheries	
Blackspot seabream (*Pagellus bogaraveo*)	NT
Rabbit fish (*Chimaera monstrosa*)	NT
*) 32–53 % of the chondrichthyan species are estimated to be threatened, 12 % are critically endangered facing a high risk of extinction. In NE Atlantic ~ 35 %, In Mediterranean ~ 57 %. EN: endangered, VU: vulnerable, NT: not threatened	

Effects of small-scale fisheries on fish stocks

Small-scale fisheries (SSF) are either artisanal (i.e. professional) or recreational and they are difficult to assess due to differences in statistics and lack of coordinated data. However, their effects on fish stocks are comparable to the commercial fisheries (e.g. Radford et al., 2018). The EU CFP defines SSF as "fishing carried out by fishing vessels of an overall length of less than 12 m and not using towed fishing gear". About 84 % of the EU-25 fleets can be considered as SSF (Guyader et al., 2013; Hyder et al., 2016) and these are largest in Greece, Italy, Spain, Portugal and France.

Recent estimates of the SSF effects on fish stocks, indicate that SSF contribution to total removals for e.g. European seabass (*Dicentrarchus labrax*), salmon (*Salmo salar*) and Pollack (*Gadus pollachius*) in Europe account for 30–43 % while SSF catches of cod (*Gadus morhua*) and Atlantic mackerel (*Scomber scombrus*) are 2–21 % (Radford et al., 2018).

The small-scale fisheries impact also the vulnerable species. According to a review of 24 case studies in the Mediterranean, in average 30 % of the caught individuals were considered vulnerable species either by international conventions, IUCN or EU Habitats Directive and 10 of 45 assessed species were categorized as threatened by IUCN (Font and Lloret, 2014; Nieto et al., 2015).

Recreational fishing is not as controlled nor as well investigated as commercial fishing.

Finally, it is likely that illegal, unreported and unregulated fishing is a common element of SSF (FAO, 2015). Font and Lloret (2014) compared catches with the minimum landing size (MLS) and found large variability between fishing areas and stocks; in some stocks even 81–90 % of catch are below MLS and hence illegal.

Bycatch of non-target species in fishing

Fishing tools are designed to catch targeted fish, but they incidentally capture also non-target marine species (also called bycatch). General practice is to discard these species back at sea, often dead. Current estimates of global bycatch amount to < 10 million t yr^{-1} (8 % of global annual catches), but this has declined by 50 % since the peak in 1980s (FAO, 2005; Zeller et al., 2018).

The majority (93 %) of discards take place in the EEZ, mainly by large-scale fisheries (FAO, 2005; Zeller et al., 2018). The quantity of bycatch strongly depends on the fishing tool where bottom trawls contribute significantly higher bycatch than other gear. Globally, shrimp and demersal finfish trawl fisheries account for over 50 % of total discards but represent ~ 22 % of total landings (FAO, 2005). EU CFP aims at gradually eliminating discards by an obligation to land the unwanted catch by 2019 (https://ec.europa.eu/fisheries/cfp/fishing_rules/discards_en). The current discard rates are estimated at 10 % in EU fisheries (Guillen et al., 2018).

In the Mediterranean Sea, one fifth (230,000 t) of all catches are discarded dead or alive depending on the type of fisheries and this figure is 10–15 % (45,000 t) in the Black Sea (FAO, 2016). Especially, the Black Sea gillnet fishery for turbot is associated with high bycatch rates of dolphins and demersal sharks (e.g. piked dogfish). The NE Atlantic has the highest discards globally together with the Northwest Pacific; they jointly account for 40 % of the world's discards (FAO, 2005).

Trawl fisheries have high bycatch rates of about 20–70 % whereas an average bycatch rate of small-scale fisheries is about 15 % of the catch or up to 49 % with the trammel nets (Gonçalves et al., 2007; Lloret et al., 2016). The majority of the trawl bycatch consists of benthic species of even 140 different species (Bueno-Pardo et al., 2017). The benthic impacts are further discussed in Chapter 3.4 (Seafloor).

Bycatch of the **vulnerable species** of marine mammals (dolphins, porpoises, whales and seals), seabirds, turtles and chondrichthyans (sharks, skates and rays) have received considerable attention due to the steep declines of many of these species' populations (OSPAR, 2017; HELCOM, 2018a). A global review of the bycatch of mammals, seabirds and turtles showed that the turtles are the most sensitive and seabirds least sensitive to be bycaught (Lewison et al., 2014). Long-lines are the main gear responsible for the bycatch of turtles, chondrichthyans and seabirds whereas mammals are more vulnerable to trawlers (FAO, 2018b). Globally, the Mediterranean Sea is among the top three bycatch areas of sea turtles and marine mammals. On a European scale, the seabird bycatch in gillnet fisheries is highest in the Celtic Seas and the southern Baltic Sea. The bycatch rates of these species are highest in gillnet fisheries, followed by long-line and trawling fisheries (Lewison et al., 2014).

A review of almost 1800 studies showed that bycatch is the major reason for population decline of 112 of the 121 assessed **marine mammal** species worldwide (Avila et al., 2018). Also, in Europe, the mammal bycatch is a severe problem particularly for dolphins (Kaschner, 2003; Mannocci et al., 2012; Birkun et al., 2014).

The Mediterranean region was identified as a global high bycatch area for the loggerhead (*Caretta caretta*) and the green sea turtle (*Chelonia mydas*), which are both classified as endangered species (Wallace et al., 2013). Bycatch of **sea turtles** in the Mediterranean has been estimated as 132,000 captures per year (ca 44,000 incidental deaths), and it is caused by gillnets, trawls, pelagic longlines and demersal long lines (Casale, 2011; Wallace et al., 2013).

Coastal gillnet fisheries cause more **seabird** bycatch than many other gear types and they are particularly widespread in the Baltic Sea and North Sea where large wintering areas of northern waterbirds are found. In the northern European marine areas, practically all the fishing vessels using gillnets are smaller than 12 m and thus not part of the vessel monitoring system which makes it difficult to assess the areas of potentially high seabird bycatch (Almeida et al., 2017). A cumulative bycatch of 90,000–200,000 seabirds are estimated annually in these regions (Žydelis et al., 2009). In the other regions, the Spanish hake fleet in the Gran Sol area, Icelandic cod, haddock and tusk fleet in the N Atlantic and Norwegian haddock and tusk fleet in the NE Atlantic have been identified among the global top 10 fleets to cause the highest levels of seabird bycatch, particularly albatrosses, petrels and shearwaters (Anderson et al., 2011). In total, 40 European seabird species are at risk from bottom set gillnets (Žydelis et al., 2013); some of them threatened (Vaughan et al., 2019).

Around 80 **chondrichthyan species** (sharks, rays and skates) are found in the Mediterranean and the Black Sea and 62 of them have been recorded in trawls (Bradai et al., 2012). Species in the shallow coastal shelves are mainly affected by bottom trawlers targeting demersal fish and crustacean species, but long-line bycatches of sharks is 10–15 % of the total catch biomass. The tuna and billfish fisheries get blue shark (*Prionace glauca*) bycatch (Davidson et al., 2015). Gillnet bycatch in the Balearic Islands is considerable for the common stingray (*Dasyatis pastinaca*), the rough ray (*Raja radula*) and the marbled electric ray (*Torpedo marmorata*) (Bradai et al., 2012).

A part of bycatch is caused by the loss of abandoned fishing gear, particularly gillnets (so-called ghost nets). Due to biofouling it has been estimated that they fish for 2–3 years but after 45 days their bycatch rate is only one fifth of the initial rate (reviewed by Graham et al., 2009). It is estimated that about 3,000 tons of fishing gear are lost annually in the Mediterranean Sea (Golik, 1997).

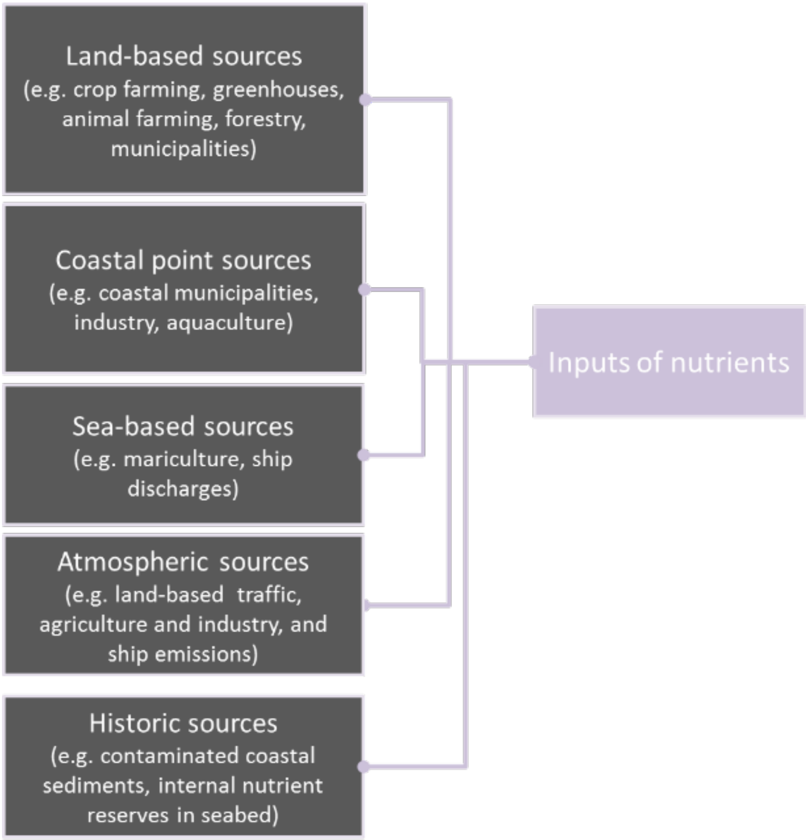
3.3 Nutrient enrichment

KEY MESSAGES:

- Eutrophication remains to be a problem of several European coastal sea areas in all the marine regions. The Baltic Sea and the Black Sea are heavily eutrophied marine regions.
- Total nutrient inputs to the four marine regions have declined, which is also visible in the level of nutrients at sea and in the direct and indirect effects of eutrophication.
- Point source inputs have significantly decreased, but inputs from diffuse sources have not, the use of agricultural mineral fertilizers is even increasing.

Urbanisation and intensive agricultural changes starting in the 1950's have led to pollution from excessive nutrients (i.e. nutrient enrichment; mainly compounds of nitrogen (N) and phosphorus (P)) (Figure 3.15). The ecological process initiated by this pollution is called eutrophication. It has become a major concern in the Baltic Sea and the Black Sea already since the 1970s and in many coastal areas of Europe (Grizzetti et al., 2011a; Strokal and Kroeze, 2013; HELCOM, 2018a), and has substantial economic consequences (TEEB, 2010). The recent EEA assessment of eutrophication gives a wider scope to the levels of pressure (EEA, 2019a).

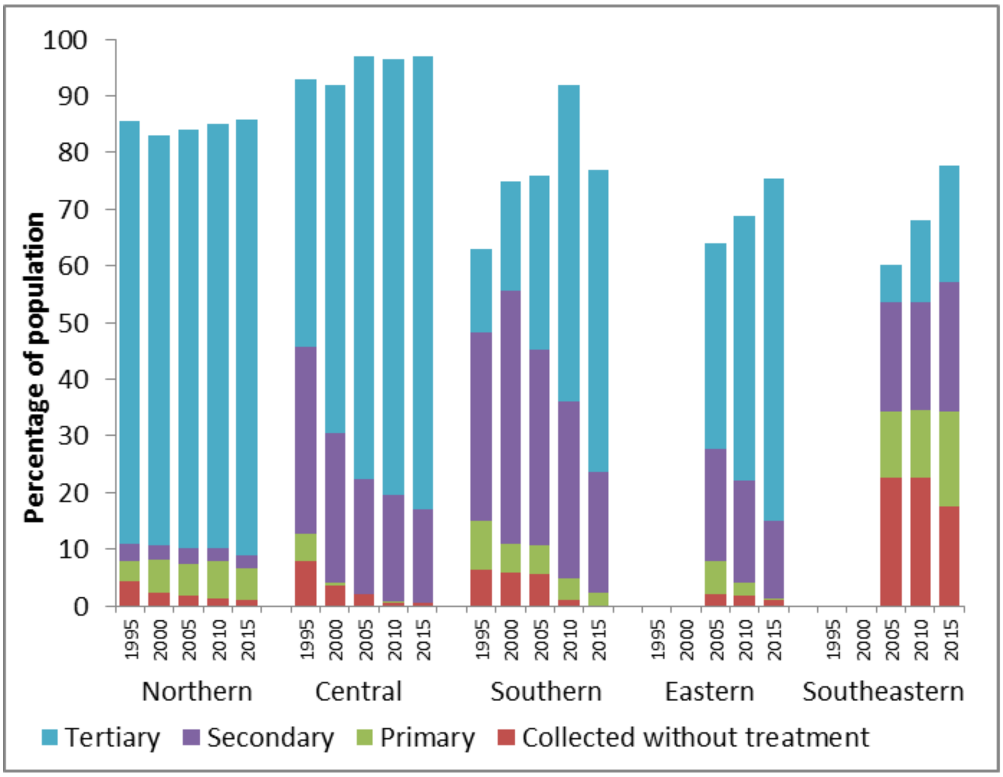
Figure 3.15: Activities causing nutrient enrichment in European seas



Inputs of nutrients

The annual N and P estimated loads to the European seas for the period 1985–2005 ranged between 4.1 and 4.8 Tg N yr^{-1} and 0.2 and 0.3 Tg P yr^{-1} (Grizzetti et al., 2011b). Standardized to unit area of the corresponding catchments the highest inputs today are to the Atlantic and North Sea, followed by the Mediterranean, the Black Sea and the Baltic Sea. This declining trend has been seen in the Mediterranean Sea, North Sea, the Black Sea (only nitrogen) and the Baltic Sea, (Grizzetti et al., 2011b; Giani et al., 2012; Moon et al., 2016, EEA, 2018a, EEA, 2019a). The decline is primarily explained by reductions in point sources but not in diffuse sources (Figure 3.16).

Figure 3.16: Progress in waste water treatment in Europe. Source: EEA, 2019i



Agriculture is the major land use activity in Europe and the driver with the highest inputs of nutrients and organic matter (Eurostat, 2017g). Phosphorus fertilizing has decreased by 20 % since 2006. Following the introduction of the Nitrates Directive (ND) in 1991 and the introduction of the National Action programmes for designated Nitrate Vulnerable Zones (NVZs), nitrogen fertiliser consumption was reduced significantly in the EU-15. In the EU-28 the use of nitrogen fertiliser per hectare is, however, not decreasing and 11 Member States have increased their N fertilizer use. This has taken place in the catchments of all the four marine regions. Nonetheless, on an EU-scale, the N and P balance in agricultural soil has decreased during the 2000s (Eurostat, 2017g).

In the Mediterranean Sea, annual N and P inputs have been estimated as 1.3 Tg N and 126 Gg P (PERSEUS – UNEP/MAP, 2015). In the region, 50 % of N and 75 % of P inputs come via rivers and the rest from atmosphere and coastal point sources to the sea. In general, the northern rivers discharge more nutrients than the southern rivers of the sea region (Strobl et al., 2009). The largest riverine inputs (in total 25 % of the total discharge) are from the Rhone and the Po.

Nutrient inputs to the Black Sea are high in comparison to the other European seas. Inputs of total N and total P were estimated in 2,000 as 640,000 tons N and 90,000 tons P (Strokal and Kroeze, 2013). The total N and P inputs in the 1990s to the northern Black Sea alone were six times higher (N) and about the same magnitude (P), respectively, than to the Baltic Sea (Borysova et al., 2005; Artioli et al., 2008). Most

Black Sea rivers drain into the northern Black Sea bringing ~80 % of dissolved inorganic nitrogen, 70 % of dissolved organic nitrogen and 50 % of particulate nitrogen to the area. Since the 1980s a 5 % decrease in riverine N inputs and a 15–20 % decrease in phosphates have taken place in the northern areas (Borysova et al., 2005; Strokal and Kroeze, 2013; daNUBS project). The N inputs have, however, increased in the southern areas. On a Black Sea wide scale, also phosphate inputs have increased as a result of increased sewage inputs (Strokal and Kroeze, 2013).

In the Baltic Sea, the N and P inputs peaked in the 1980s and have since declined towards regionally defined target values (HELCOM, 2018c). At a regional scale, the current annual total input of nutrients to the Baltic Sea amounts to about 826,000 tonnes of N and 30,900 tonnes of P which account for inputs 7 and 44 % above the target values, respectively. Current N sources are from atmospheric inputs (27 %; shipping, road transportation, energy production, and agriculture), coastal point sources (4 %), riverine inputs (70 %). P inputs are mainly from the rivers (95 %) while the coastal point sources have today played only a minor role (5 %). In the riverine load, agriculture and other diffuse inputs are the main nutrient sources to the Baltic (47 % N and 36 % P), point sources in the catchment area constitute 12 % and 24 % of N and P inputs, and the rest originates either from transboundary or natural sources (HELCOM, 2018c). The largest relative decreases in inputs of N and P over recent decades have occurred in direct point sources.

Inputs to the Iberian coast and Bay of Biscay are about 0.3 Tg N yr^{-1} and 12 Gg P yr^{-1}, and have decreased since 1997 (OSPAR, 2017). Annual N inputs to the Greater North Sea are 1.5 Tg of which 24–38 % is atmospheric. Reduction in N inputs since 1990 has taken place but it has been weak (OSPAR, 2017). P inputs to the Greater North Sea are 40 Gg yr^{-1} which is half of the amounts seen in 1990. P inputs have halved since 1990 to 40 Gg yr^{-1} and the decrease is still about 1.5 Gg yr^{-1}.

Level of eutrophication in Europe's seas

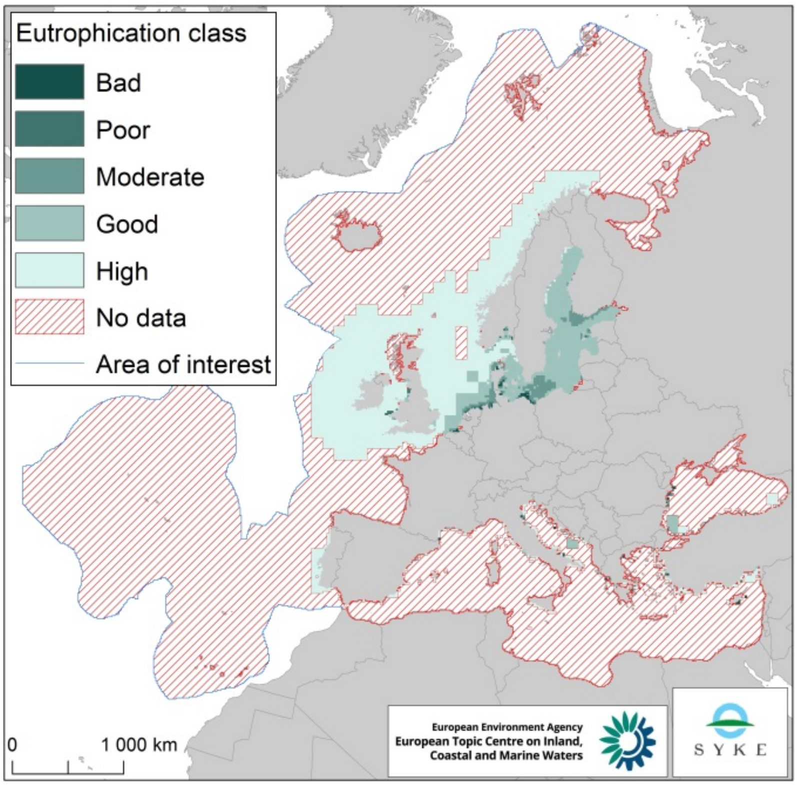
The integrated assessment of eutrophication in Europe's seas showed that 1,208 out of the 2,956 assessed sites (41 %) were identified as eutrophied (EEA, 2019a). The assessed sites were predominantly in coastal waters.

The recent HELCOM assessment showed that the entire Baltic Sea suffers from eutrophication (HELCOM, 2018a). A similar result was found by Europe's integrated assessment (EEA, 2019a).

In the Black Sea, Borysova et al. (2005) estimated that all the western and north-western coastal waters are eutrophied down to near a 100 m depth below which the basin is anoxic. Yunev et al. (2017) showed that annual primary production is near 1.8 times higher than in the 1960's for the entire region. The EEA integrated assessment supported this result and showed that 60 % of the assessed sites were eutrophied. Nutrients are supplied to the area by Europe's 2nd and 3rd largest rivers, the Danube and Dnieper.

The integrated assessment of Europe's seas indicated that only 16 % of the Mediterranean assessed sites show eutrophication. The data gaps were, however, wide in Croatia, Cyprus, France, Greece, Italy, Malta, and Spain (Figure 3.17).

Figure 3.17: Integrated assessment of eutrophication in Europe's marine area. In the southern sea areas the assessment is done for coastal waters (not properly visible). See Appendix A for the data layer description.



Source: EEA, 2019a.

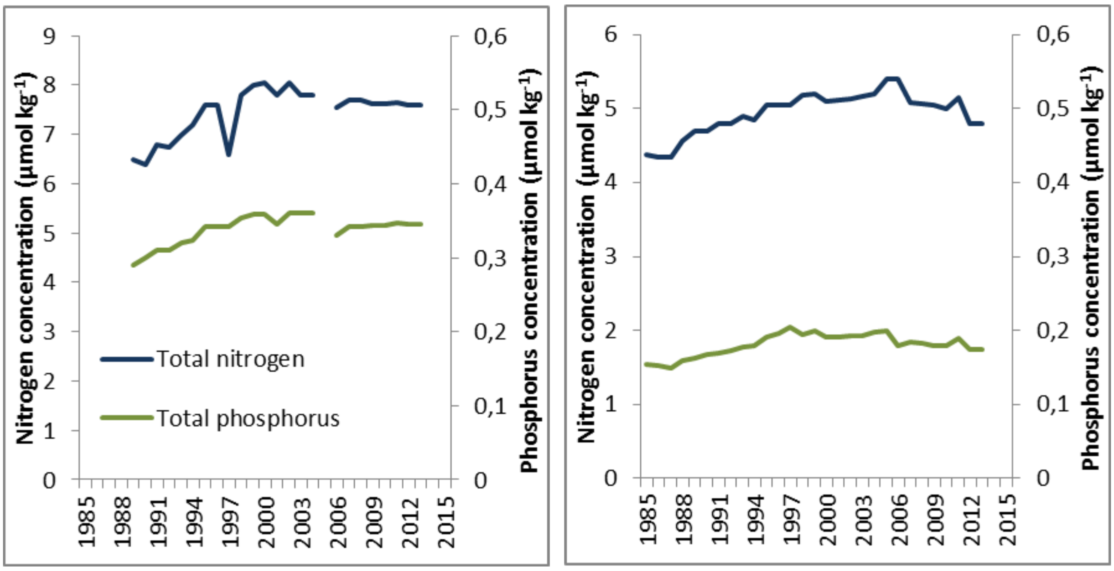
In the NE Atlantic, eutrophication is found only from coastal seas. The European integrated assessment indicated that the Southern North Sea and coastal areas of Celtic Seas are eutrophied. According to the OSPAR eutrophication assessment (OSPAR, 2017) the Norwegian Sea and Barents Sea (Arctic Waters) are not eutrophied but in the Greater North Sea, Celtic Seas, and Bay of Biscay more than 100 assessment areas in inshore and coastal waters – and a few large offshore areas – were classified as eutrophic or potentially eutrophic. This covered 117,000 km^2 of the Greater North Sea area, 2,600 km^2 of the Celtic Seas and 4,700 km^2 of the Bay of Biscay. The state has, however, improved as a 30 % smaller marine area was assessed as eutrophied since the early 2000s (EEA, 2019a).

Nutrient levels at sea

In the coastal waters under the EU WFD N and P levels indicated eutrophied conditions in ~ 60 % and 78 % of the coastal water bodies, respectively (EEA, 2019a).

In the Baltic Sea, all the sub-basins had N and P concentrations exceeding the thresholds (HELCOM, 2018a). In the Black Sea, 48 % of the assessed sites indicated nutrient levels as too high. The Mediterranean is one of the most oligotrophic seas in the world and most of its biological productivity takes place in the euphotic zone (UNEP/MAP, 2017). Still, the coastal waters are affected by high nutrient levels; >40 % of the assessed sites have levels higher than that of the thresholds (EEA, 2019a). The Mediterranean Sea has a nutrient gradient from the oligotrophic eastern Levantine Sea to the higher nutrient concentrations of the Western Mediterranean Sea. Coastal eutrophication is visible in the western and north-western Adriatic Sea, SE coastal areas outside Cairo and Alexandria, Northern Aegean Sea, Gulf of Lions and Gulf of Gabès (UNEP/MAP, 2017). The inputs as well as nutrient concentrations at sea have declined (Figure 3.18).

Figure 3.18: Total nitrogen and phosphorus concentrations in the western Mediterranean in 1989–2015 and eastern Mediterranean in 1985–2015. The shading indicates the 95 % confidence intervals. Re-drawn from Moon et al., 2016.



In the NE Atlantic, the state of nutrient levels exceeds thresholds only in 13 % of the assessed sites (EEA, 2019a). The levels are highest in the southern North Sea. The N and P concentrations have decreased significantly in the southern North Sea and, in case of nitrogen only, in the Kattegat, Sound and offshore areas of the Skagerrak since 1990 (OSPAR, 2017).

Direct eutrophication effects

Increased nutrient concentrations are often first seen as enhanced phytoplankton growth and then as a consequent decrease in water transparency. The EU Member States' recent assessment of these two indicators in the coastal waters showed that 56 % of the sites have eutrophic phytoplankton conditions and 72 % exceed the water transparency thresholds (EEA, 2018b).

In the Baltic Sea, chlorophyll, cyanobacterial blooms and water transparency indicate a eutrophied state in all the areas except the Sound and the Kattegat which are in the transition zone to the North Sea (HELCOM, 2018a; EEA, 2019a). The chlorophyll concentrations have shown improvement in recent years in the western areas and the decrease in water transparency has levelled off in all the areas.

In the Black Sea phytoplankton biomass increased 30-fold between the 1950s and 1980s and the species composition shifted from diatoms to a dominance of dinoflagellate and cyanobacteria (Borysova et al., 2005). The phytoplankton biomass has decreased since, but still indicates a eutrophic state (Yunev et al., 2017). Red tides (i.e. *Noctiluca*, *Prorocentrum cordatum*) are frequent in the region.

In the Mediterranean, the chlorophyll-a concentrations indicate mainly a good state, but higher concentrations in coastal areas indicate eutrophication in the western and north-western Adriatic, off the Egyptian coast, Gulf of Gabès, Northern Aegean Sea, and outside bigger cities in Spain and France. The chlorophyll concentrations have declined since the 2000s, at least in the Adriatic Sea (Giani et al., 2012).

In the NE Atlantic, the chlorophyll-*a* concentrations are up to ten-fold higher in the coastal areas than offshore (OSPAR, 2017). The highest concentrations are observed along the continental coast of the southern North Sea. Most of the assessed areas indicated stable conditions, but the offshore southern North Sea, coastal Skagerrak and the Sound areas showed decreasing concentrations while increased concentrations were seen in the offshore Celtic Sea (OSPAR, 2017).

Indirect effects of eutrophication

Eutrophication indirectly affects the marine benthic ecosystem via increased organic matter, decreased water transparency and enhanced oxygen demand. Therefore, the state of aquatic vegetation, benthic communities and sea-floor oxygen are important signs of eutrophication. Oxygen concentrations above 6 mg L^{-1} are usually considered to support marine life with only the most sensitive species avoiding it, while concentrations less than 2 mg L^{-1} are considered hypoxic and to cause severe problems (EC, 2003; Vaquer-Sunyer and Duarte, 2008).

Around 60–70 % of the coastal water bodies indicate a disturbed state of these three indicators, but the large number of unassessed areas limits the conclusion of the eutrophication state (EEA, 2018b). The EEA eutrophication assessment showed that 27 % of the assessed sites are eutrophied by these three indicators (EEA, 2019a). There are large differences among the regions, as the rate is 65 % in the Baltic, 47 % in the Black Sea, 11 % in the Mediterranean, and 7 % in the NE Atlantic.

About one fifth of the Baltic Sea is hypoxic (<2 mg L^{-1} O_2; HELCOM, 2018a), and oxygen depletion is even increasing in the central parts of the Baltic Sea (HELCOM, 2018a). The recent assessments of benthic invertebrate communities in the Baltic indicated that wide areas of the offshore seafloor above halocline and coastal water bodies are generally in a good state (HELCOM, 2018a; EEA, 2018b).

The Black Sea is permanently stratified by a halocline at the depth of 100–150 m, causing anoxia below that depth. According to the Copernicus ocean state report, the oxycline has risen from 140 meters in 1955 to 90 m in 2010–2015 (von Schuckmann et al., 2018). In shallower areas, severe seasonal summer-time hypoxia takes place at 5–30 m depth in the NW slope of the region located between the Danube and Dniester discharge area (Zaitsev and Mamaev, 1997). In 2000, 14 000 km^2 of the seabed in this area was hypoxic (Strokal and Kroeze, 2013) and caused a crash of benthic fauna (e.g. blue mussels) and macroalgae (e.g. the large *Phyllophora* meadows and the brown alga *Cystoseira barbata*) and fish stocks (Borysova et al., 2005; Yunev et al., 2007; Capet et al., 2013). Borysova et al. (2005) report that the *Phyllophora* red algae meadows with the specific associated faunal communities still flourish in the eastern coastal waters of the basin, where no big rivers drain into the sea. Sediment cores from the western Black Sea area show that the organic enrichment started in the 1970s but has decreased in recent years which may indicate improvement in the eutrophication state (Roepert et al., 2015). Some recovery of benthic fauna has been reported in the Romanian coastal areas (Friedrich et al., 2013).

In the Mediterranean, hypoxic conditions have been found only in coastal areas of the Adriatic Sea, Northern and Western Aegean Sea, Eastern Ionian Sea and the Gulf of Lion (EEA, 2019e). The eutrophication of the Adriatic Sea started in the 1970s, but the hypoxic events have become rarer since the 1990s–2000s (Giani et al., 2012; Djakovac et al. 2015).

In the NE Atlantic, no area is considered hypoxic although reduced oxygen concentrations are also found (OSPAR, 2017). Consequently, the coastal benthic invertebrate communities and aquatic vegetation indicate generally a good state in relation to the enrichment of organic matter and nutrients (OSPAR, 2017).

3.4 Damage to seabed habitats

KEY MESSAGES:

- Long term seabed habitat loss from sand and gravel extraction, construction of offshore installations, wind farms, coastal construction and dumping at sea is found in below 3 % of the entirety of the European sea area.
- Physical disturbance of habitats is wider distributed. About 23 % of the entire European seabed and 43 % of its shelf area habitats are under some form of physical disturbance. However, evidence suggest that there is uncertainty in the assessment, and this may amount to even 86 % in parts of the Greater North Sea and 93 % in the Baltic coastal strip.
- Bottom trawling is the most extensive human activity impacting the European continental shelf (35 % of the shelf area).

Seabed provides valuable resources to societies and industry in terms of food, raw materials, energy and space (e.g. fisheries). To obtain these benefits, we undertake several activities that disturb the seabed and its habitats by changing geological, physical and chemical conditions or directly affect the benthic biology.

The lost or disturbed seabed is not evenly distributed in Europe; the coastal areas are under higher pressure than the offshore areas. About 74 %–93 % of the assessment units in the coastal strip faces this pressure in the four regions whereas 41–71 % of the shelf and only 1–9 % of the beyond shelf seabed is physically disturbed. The deep sea is, however, beginning to face anthropogenic pressures, too. A review by Ramirez-Llodra et al. (2011) suggests that the overall anthropogenic impact in the deep sea is increasing and has evolved from disposal and dumping in the late 20th Century to exploitation in the early 21st Century.

Loss of benthic habitats

Habitat loss is an extreme pressure on the marine ecosystem which was defined to include all impacts on the seabed which take > 12 years to recover; a time span influencing even long-living marine mammals and seabirds. Habitat is lost if its substrate, morphology or topography is permanently altered. Activities causing such damage are sand and gravel extraction, removal of hard substrate or biogenic reefs, capital dredging of the seabed, disposing waste material and dredged matter and all kinds of construction activity in or over the seabed (Figure 3.19).

In the period of 2011–2016, Europe's seas have experienced habitat loss in 2.7 % of the assessment units (Figure 3.20). As the assessment was made in 10 km × 10 km cells, we cannot estimate the areal habitat loss. All the activities causing loss of habitats are smaller in area than our assessment units. As most of the activities causing this pressure take place in coastal waters, we calculated that in the 0–12 nm zone 25 % of the assessment units have experienced habitat loss.

The greatest habitat loss – in relation to regional sea area – has taken place in the Baltic Sea (14 % of the assessment units), followed by the Mediterranean (3.7 %), the NE Atlantic (2 %) and the Black Sea (1.5 %). In the Baltic Sea, HELCOM estimated a ~ 1,500 km^2 loss of benthic habitats, which is less than 1 % of the actual sea area (HELCOM, 2018a).

Habitat loss is typically found outside cities and at ports, deposit sites and aggregate extraction sites. The offshore oil and gas installations in the North Sea are the only wider offshore activity causing habitat loss (Figure 3.20).

Figure 3.19: Activities causing physical loss of seabed

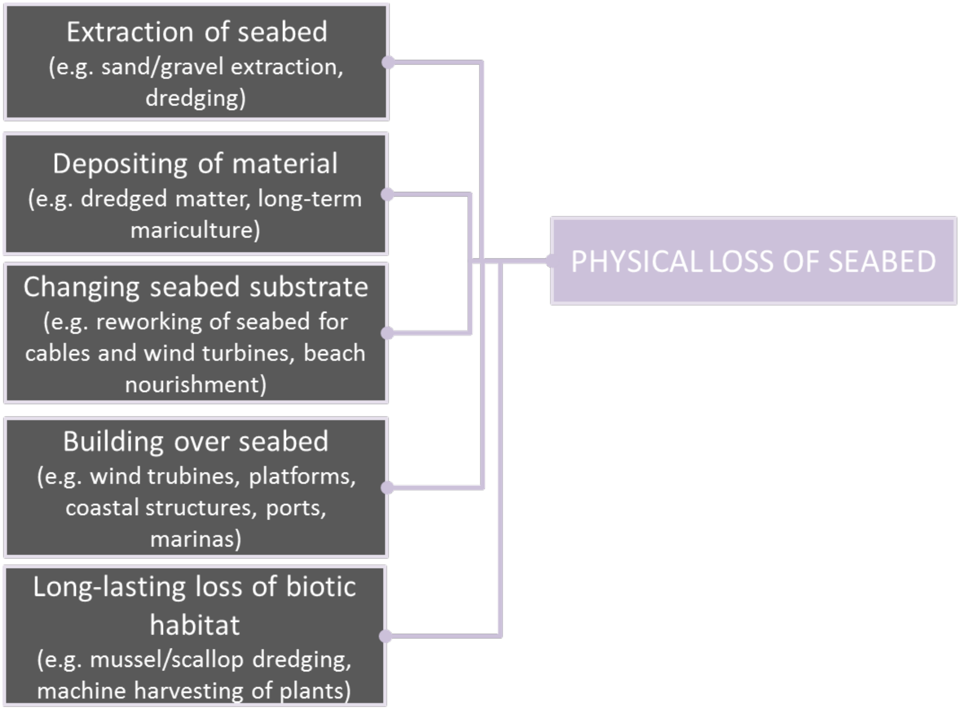
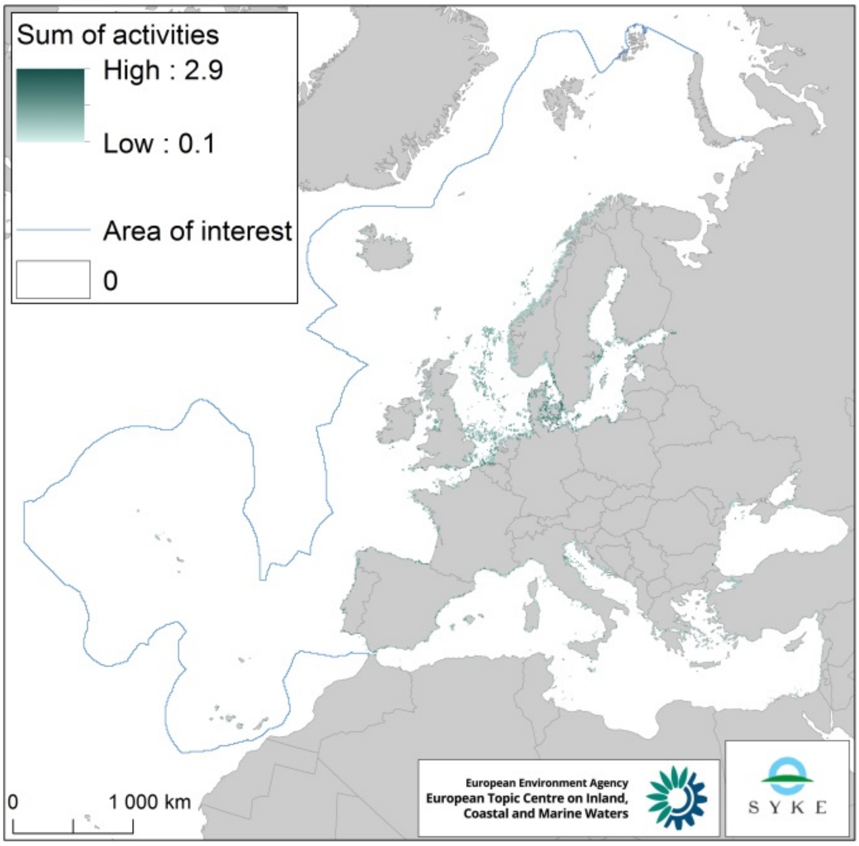


Figure 3.20: Distribution of physical loss to seabed. See Appendix A for the data layer description

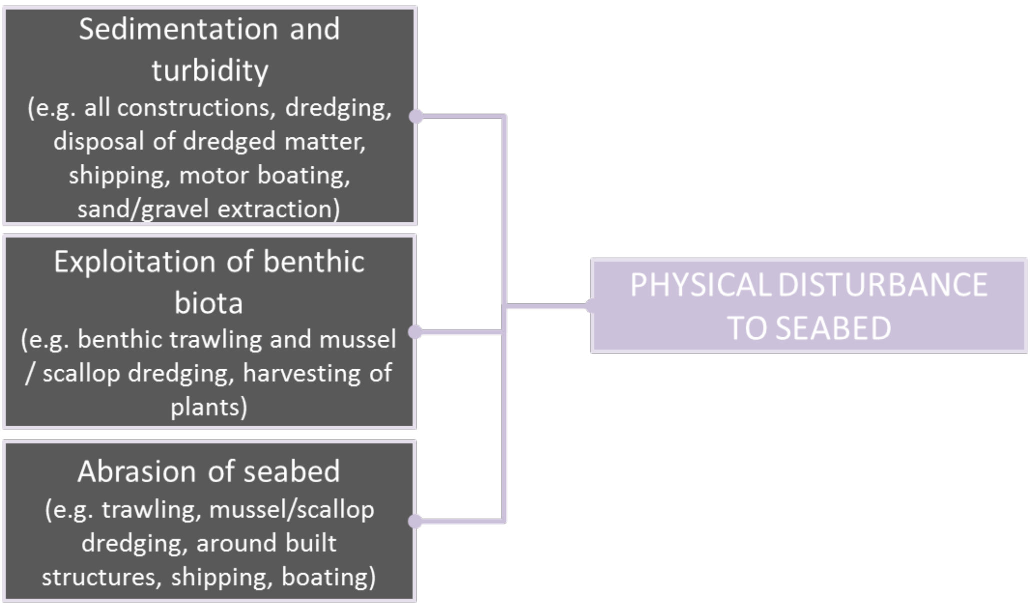


Disturbance to the seabed

Several human activities disturb the seabed either directly or indirectly (Figure 3.21). Alteration of benthic living conditions as a result of increased sedimentation or attenuation of light penetration, abrasion of the seabed and exploitation of benthic biota – temporarily disturb the benthic habitat quality. Sedimentation caused by dredging operations, demersal fishing gear, sediment disposal and construction projects spread sediments to the water column and cause direct sedimentation disturbance, which attenuates away from the activity zone. Abrasion of the seabed by benthic trawling or mussel and scallop dredging damages abiotic and biotic structures, whereas indirect abrasion is caused around built structures by altered current regimes or in shallow waters by propeller currents of maritime traffic.

In this assessment, no cut-off minimum is given to the amount of benthic disturbance, i.e. even lowest disturbance is included in the figures. With this precondition, the distribution of benthic disturbance is fairly high in the European seas: 3.5 million km^2 (~ 23 %) of the assessed sea area (Figure 3.22). In relation to areas of the sea regions, the Baltic seabed is more disturbed than other regions (79 % of the assessment units). The spatially higher resolved HELCOM assessment sharpened this score down to 40 % and showed that the disturbance was much more extensive in the sub-basins where bottom-trawling is practiced and sand and gravel extraction is more intensive (HELCOM, 2018a). In the NE Atlantic, 44 % of the shelf and coastal area was under some form of physical disturbance, but deeper areas have only very little disturbance (Figure 3.22). In the Mediterranean, our analysis showed 69 % coverage in the narrow shelf and coastal areas around the sea and in the shallower sea around the Balearic Islands, Malta and Sicily as well as the Adriatic Sea and the Aegean Sea. In the Black Sea, the pressure is widest in the Sea of Azov and NW parts; a total of 55 % coverage in the shelf and coastal zones.

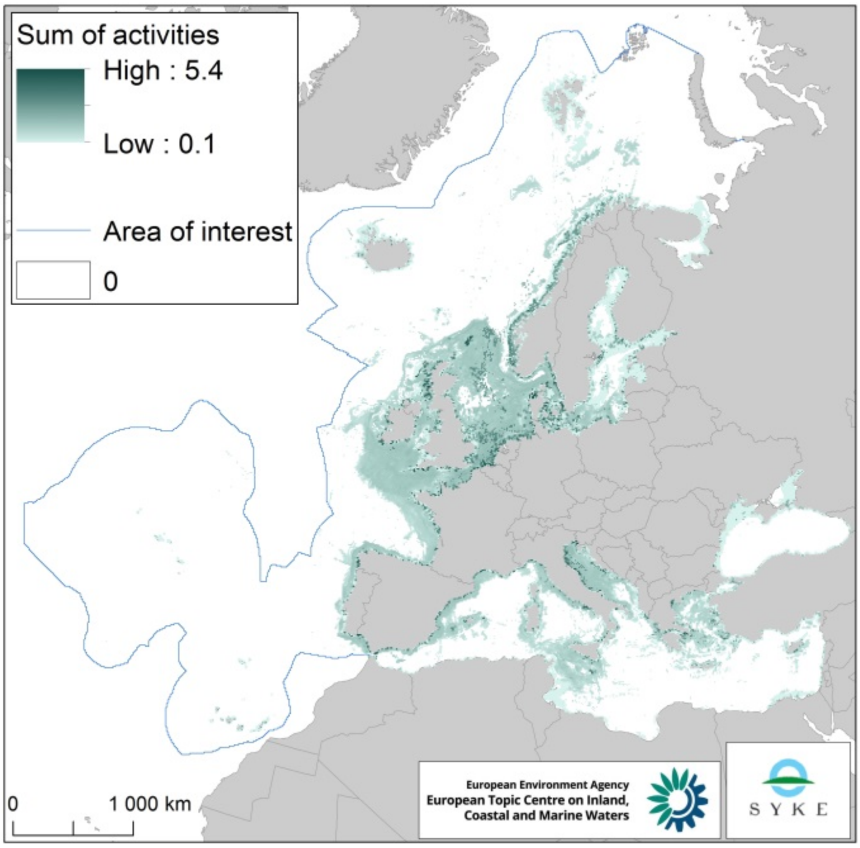
Figure 3.21: Activities causing physical disturbance to the seabed



Bottom trawling is the widest impacting activity

The activity responsible for the spatially widest disturbance is the demersal fishery, especially bottom trawling (Figure 3.23). The bottom trawling effects can be divided to blunt impacts (dislodgement or crushing), line shear by a narrow object and hooking (snagging animals) (Clark et al., 2016).

Figure 3.22: Distribution of physical disturbance to the seabed. The relative scale of intensity does not indicate the level of effects on the benthic environment. See Appendix A for the data layer description



Secondary impacts consist of siltation of resuspended sediment plumes. The effort of the demersal fishery has greatly declined since the peak years in the 1960–80s (Thurstan et al., 2010), but it is still the major contributor to seabed disturbance in all the European marine regions (UNEP-MAP, 2012; Micheli et al., 2013; OSPAR, 2017; HELCOM, 2018a).

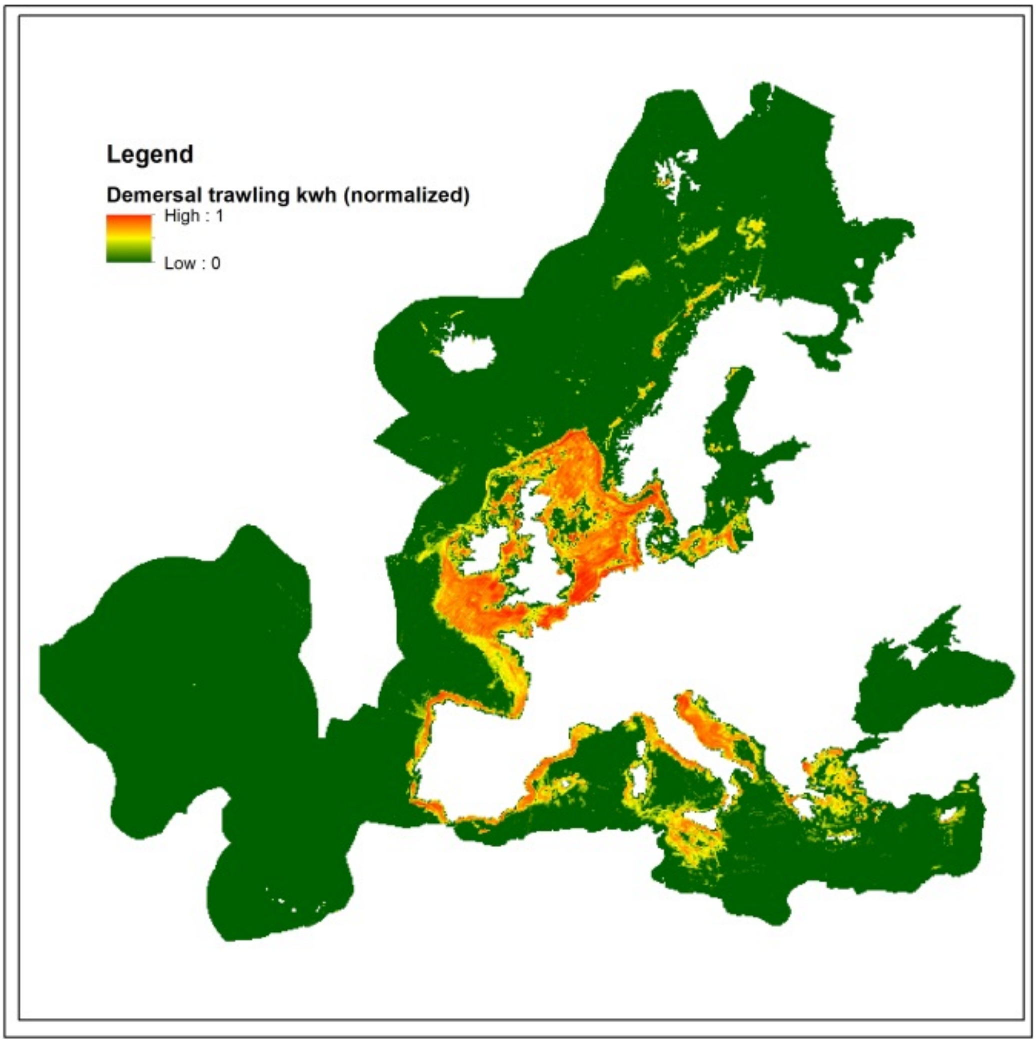
In this assessment, the effort of the demersal fishery was estimated per 10 km × 10 km assessment units. With this scale, 35 % of the shelf area – where most of the trawling takes place – in the four regions was trawled at least once during 2011–2016. However, the areas of highest effort take place in the North Sea (Skagerrak, Shetland and southern North Sea), around Spain and the western Adriatic Sea (Figure 3.23; see OSPAR, 2017, for detailed analyses). In the Baltic Sea, bottom trawling takes place only in the southern sub-basins below 57°N. In the Mediterranean, bottom trawling exerts pressure on all northern and western coasts, but the highest pressure is exerted on the western margin of the Adriatic Sea, the Italian Ionian Sea and the Spanish east coast. In the Black Sea, the demersal fishery takes place in the coastal areas above the halocline.

The effects of bottom trawling can be seen in benthic diversity. In the NE Atlantic, the Margalef diversity index of the benthic community quality indicated that intensive trawling caused lower benthic diversity compared to less trawled areas (OSPAR, 2017). Biodiversity studies in trawled areas typically show a decrease in sessile and fragile species such as corals, sponges and echinoderms on the impacted seafloor (Ramirez-Llodra et al., 2011).

The effects are found to be severe in deeper sea areas of the upper continental slopes and sea mounts (from 200 to 3,100 m; Ramirez-Llodra et al., 2011, Puig et al., 2012). Trawling over the deep-sea corals breaks up the reef-like structures which may be even thousands of years old and their recovery may take decades or centuries. Typically, the recovery of benthic habitats takes 2 to 6 years but on coarse sea-floor substrates the recovery may last even 17 years (Hiddink et al., 2017). Trawling of deep-sea species has been practiced since the 1930s while deeper depths were reached after the 1960s. The trawling-induced sediment displacement causes smoother sea-floor morphology over time in comparison to non-trawled areas. This is especially visible in tributary valleys of the continental slope where trawling-induced sediment transport changes the topography (Puig et al., 2012).

A recent meta-analysis of the effects of bottom trawling on benthic communities showed that hydraulic dredges are the most impacting trawling type, depleting 41 % of biota on each pass and penetrating on average 16 cm into the sediment (Hiddink et al., 2017). Other gear are less impacting: towed scallop dredges, beam trawls and otter trawls removed 20, 14 and 6 % of biota per pass, respectively, with a 2.4–5.5 cm sub-surface disturbance.

Figure 3.23: Bottom trawling areas in Europe's seas. See Appendix A for the data layer description.



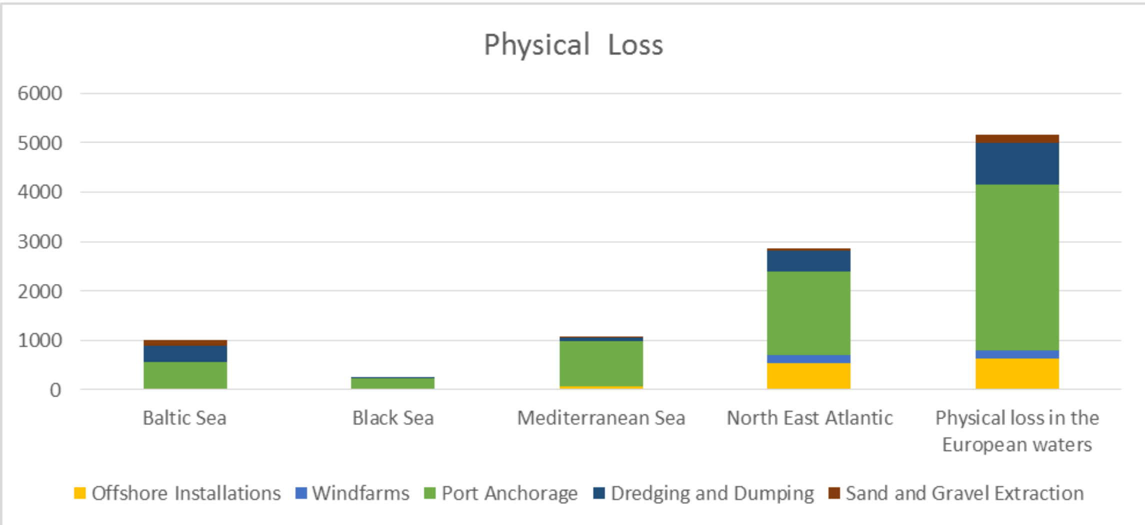
Although the bottom trawling fishery is not generally considered to cause habitat loss, an exception may be the hard substrata on seamounts where sessile benthic communities are regarded as 'vulnerable marine ecosystems'. This habitat is highly susceptible to damage by bottom fishing gear and the fish stocks are slow to recover and can be rapidly depleted due to the life-history traits and behaviour of the species (ICES, 2017b).

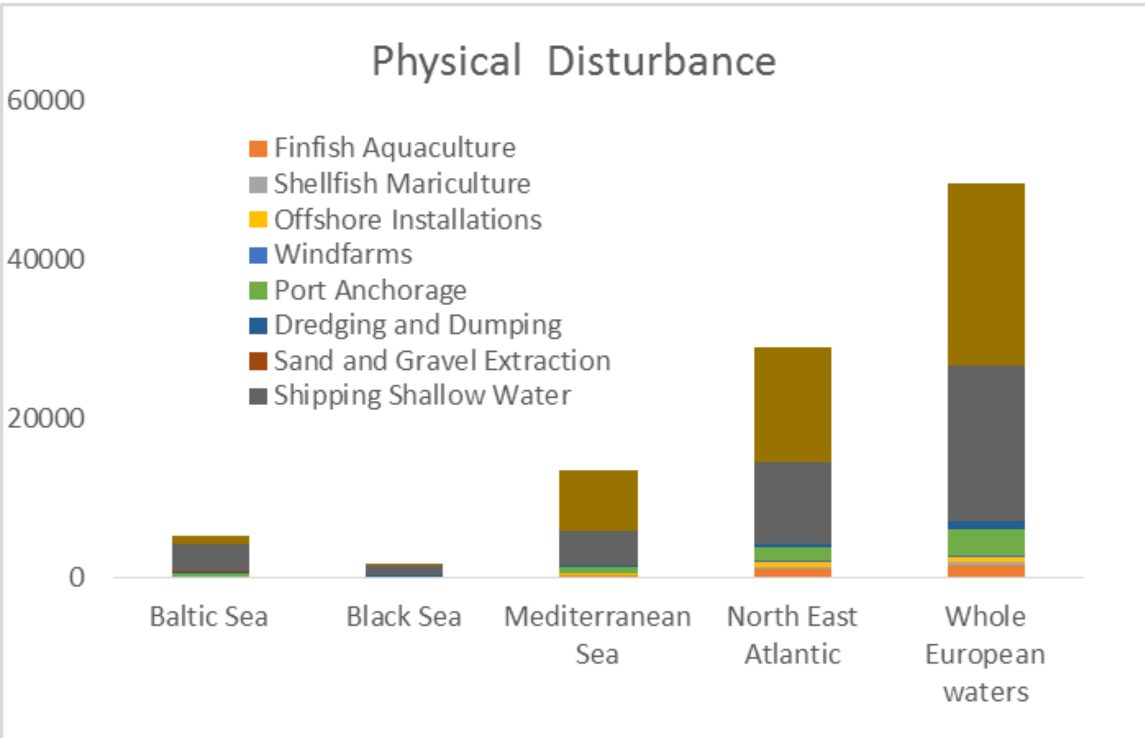
Local pressures causing loss and disturbance of the seabed

Human activities causing local loss of habitats or disturbance to the seabed and its biota can be categorized into sea-floor exploitation (extraction of mineral resources and harvesting of seaweeds), construction of offshore installations (e.g. oil and gas platforms, pipelines), wind farms, coastal structures (e.g. related to maritime traffic – dredging of shipping and boating lanes, harbours, anchoring sites, abrasion of shallow areas) and dumping (e.g. dredged spoils and other waste). Constructions can also provide some benefits, including the creation of new habitat areas, extension of feeding times to both bird and fish species, and area closures from trawling (associated with the presence of submerged cables and pipelines) (Vaissière et al., 2014).

Figure 3.24 links human activities to physical pressures impacting on the seabed. A summary of the development of these activities is given in Chapter 2.

Figure 3.24: Seabed area (km^2) estimated as physically lost (A) or potentially disturbed (B). The area is also divided between different causes of loss and disturbance.





Impacts of physical pressures on habitats

Human activities causing loss of a specific habitat have different impacts on the biota, depending on the habitat type and the physical conditions at site. For example, building over a soft or sandy substrate (e.g. a seagrass meadow) will replace the habitat and its biota with an artificial hard substrate and its associated biota, whereas building over a rocky habitat will not completely change the fauna and flora. Artificial structures such as seawalls and piles host high faunal diversity but that is still lower than that found naturally on rocky reefs. Moreover, the diversity does not represent the natural species community, and artificial structures have a higher diversity of NIS (Bulleri and Chapman, 2010; Mayer-Pinto, 2017).

Sedimentation and turbidity have high impacts on any vegetated (infralittoral and circalittoral) habitats. For example, coastal structures have been shown to increase rates of sedimentation on nearby habitats (Bertasi et al., 2007).

Deeper muddy bottoms are likely least affected by extra sedimentation, as they are mainly characterized by burrowing organisms, but abrasion by demersal trawls leaves deep tracks which take long to recover. Shallow and sheltered muddy areas are typically dense meadows of seagrasses which are very sensitive to any disturbance in water quality, over-sedimentation or fragmentation (Table 3.3).

In the deep seabed, the sedimentary slopes, seamounts, canyons, cold-water corals and oxygen minimum zones are the most impacted habitats with the current human activities (i.e. bottom trawling, bottom long lines, ghost nets and warming) (Ramirez-Llodra et al., 2011).

Hard seabed surfaces are particularly vulnerable to sedimentation as sessile organisms are the characteristic feature of the habitat. The amount of damage depends on water currents which may further clean the surfaces if the sediment load is not too high. Shallow hard substrates are also inhabited by macroalgae which demand specific light conditions and are affected by turbidity.

Table 3.3 Estimated area of potentially disturbed habitat in Europe's sea area

Habitat type	Disturbed area (% of entire habitat area). Disturbed habitat is defined as the 90th percentile of the combined effects
Sandy habitats: • infralittoral • circalittoral • offshore circalittoral	 19 % 8 % 24 %
Muddy habitats: - infralittoral - circalittoral - offshore circalittoral	 7 % 18 % 33 %
Mixed habitats: - infralittoral - circalittoral - offshore circalittoral	 7 % 14 % 8 %
Coarse habitats: - infralittoral - circalittoral - offshore circalittoral	 12 % 8 % 24 %
Rocky habitats: - infralittoral - circalittoral - offshore circalittoral	 3 % 2 % 8 %
Bathyal	8 %
Abyssal	< 1 %

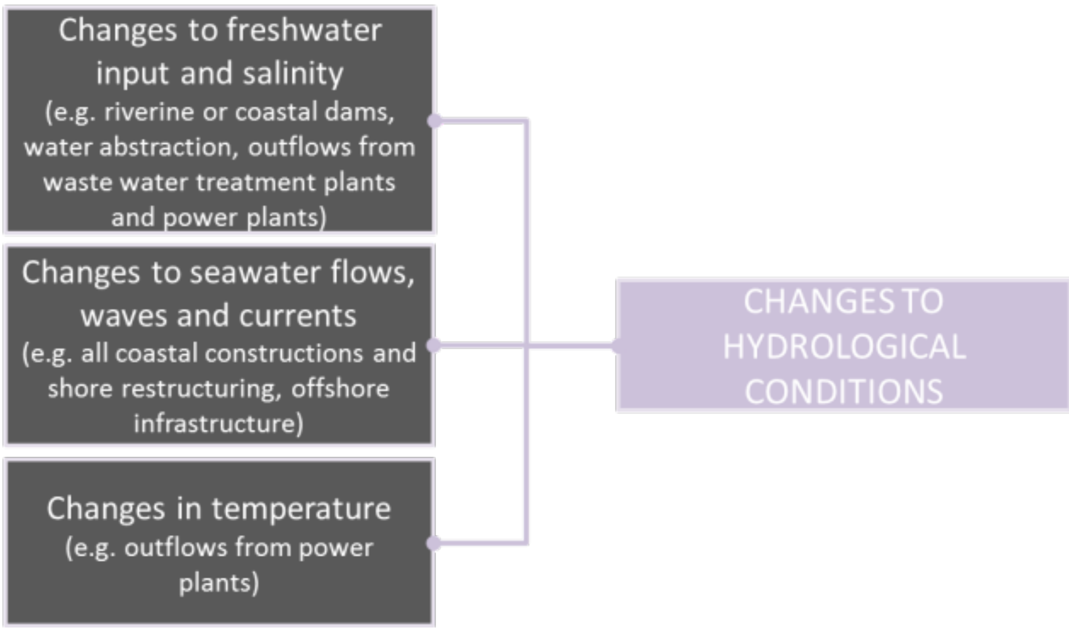
3.5 Changes in hydrological conditions

KEY MESSAGES:

- Coastal developments (e.g. coastal construction and shore protection in urban and industrial areas) affect water movement, change salinity or seawater temperature.
- About 9 % of Europe's coastal strip is affected by altered hydrological conditions.
- The pressure is highest along the coasts of the Baltic Sea and the Mediterranean.
- The hydrological changes are predicted to increase due to further development of coastal regions with an increase in maritime activities.
- Pressures from climate change are expected to increase, causing additional adverse effects in coastal areas.

The changes in hydrological conditions are often understood as altered water movement, salinity or seawater temperature (Figure 3.25). Coastal and offshore structures modify currents, wave regimes and, in case of coastal bays, water renewal times (Bertasi et al., 2007). The water renewal time may also affect the salinity and temperature of a coastal area. In addition, salinity is affected by altered freshwater inputs (decreases or increases), water abstraction and coastal infrastructure. Seawater temperature is also increased locally in the vicinity of warm water outflows from nuclear and fossil fuel power plants (see Chapter 3.8). Potentially these changes could affect entire regional seas such as the Baltic Sea and Black Sea if their semi-enclosed water exchange were altered. Also, the hydrological effect of the Suez Canal on the Mediterranean Sea could potentially be considered under this pressure.

Figure 3.25: Human activities causing changes in hydrological conditions

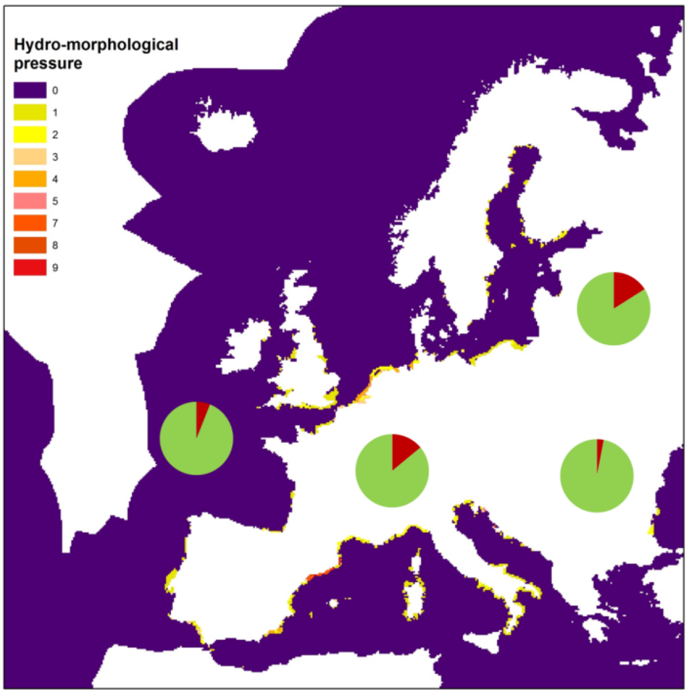


Europe's coastline is being modified by seawalls, breakwaters, groins, timber fences, revetments, protective islands, surfing reefs, beach dewatering, beach nourishment, dune stabilisation, etc. (Pranzini et al., 2015). While not all of these structures affect hydrography, it is evident that most of the coastal development altering wave exposure is not captured in the spatial analyses of this assessment. According to the Member States reporting of hydro-morphological status of coastal waters, ~ 9 % of the coastal strip is affected by the pressures causing hydro-morphological changes (Figure 3.26).

Wave and tidal energy structures induce changes to the prevailing hydrographical conditions (e.g., wave exposure), which can then alter the flow of sediments and the feeding conditions for coastal bird species and fish (Frid et al., 2012). However, such constructions can also provide some benefits, including the creation of new habitat areas, extension of feeding times to both bird and fish species, and area closures from trawling (associated with the presence of submerged cables and pipelines) (Frid et al., 2012; Vaissière et al., 2014; Carter & Burnett, 2015; NIRAS, 2015).

According to this report, about 14–16 % of the coastal strip in the Mediterranean and the Baltic Sea, 6 % of the NE Atlantic, and 3 % of the Black Sea were under this pressure (Figure 3.26). We estimated this for those Member States which had reported hydro-morphological alterations and assumed that coastal development in non-EU-countries is of the same magnitude.

Figure 3.26: Map of the pressure 'Changes in hydrological conditions'. The pie charts estimate the share of coastal strip being under this pressure in each of the marine regions (red = pressure, green = no pressure). For data description, see Appendix A.



The marine habitats and species are sensitive to changes in wave characteristics, salinity and temperature. These are among the main physical factors determining benthic species composition in the marine environment. An assessment by European experts indicated that seagrass meadows, saltmarshes, cold water coral and coralligenous algae are particularly sensitive marine features to this pressure (Appendix C). In general, also all other assessed shallow-water habitats were relatively sensitive to hydrological changes.

The hydrological changes are predicted to increase in future as human development of coastal regions and shipping and other maritime activities increase (OECD, 2016). Also, the more frequent flood and storm events and sea level rise will lead to the construction of enhanced protective structures in coastal areas (EEA, 2017a, and 2017b). While the increased occurrence of flood and storm events has been mainly predicted to the northern European shores, sea level rise has been observed in all the European sea regions (EEA, 2017b).

Climate change may accelerate construction in coastal areas (e.g. due to building additional coastal protection) and aggravate effects due to additional changes in sea temperature (often observed as the sea surface temperature, SST), ocean acidification (OA), sea level rise (SLR), and changes in salinity (Nagelkerken and Munday, 2016).

3.6 Contaminants

KEY MESSAGES:

- 93 % of the assessed area in Europe's seas are contaminated by hazardous substances.
- Levels of contamination are declining in many areas and increased contamination was found in very few sites only.
- Contamination is highest in coastal waters; hazardous substances accumulate on the seabed, which cause a high risk to benthic fauna.
- The European coastal and marine waters are polluted by a few ubiquitous substances, such as mercury, and persistent organic pollutants, such as PCBs and brominated flame retardants.
- Some ubiquitous substances accumulate in fish and seafood and may also become a source of toxic pollutants for humans.

The EEA assessment of hazardous substances (EEA, 2018d) indicated that 93 % of the assessed 1,511 sites have a contamination problem. The contamination problem is assessed if any EU Priority Substance or a selected contaminant exceeds its threshold value. In Figure 3.27 the problem areas are visible mainly on the coasts, where also most of the monitoring takes place. The 'one-out all out' approach was used in this analysis.

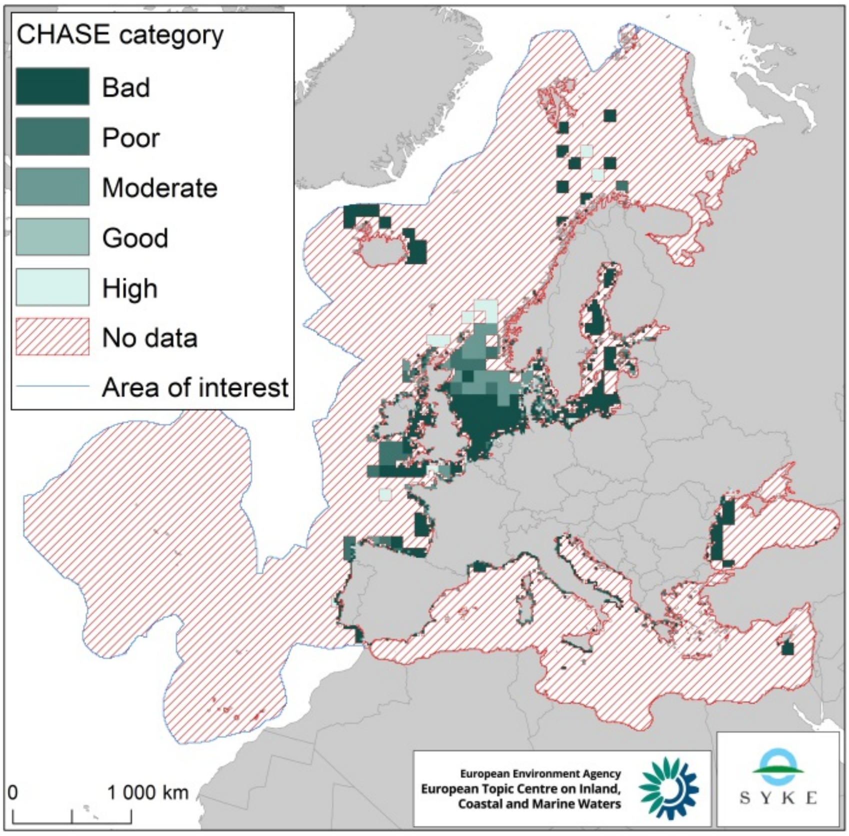
In the Baltic Sea, 94 % of seawater assessments indicated a problematic contamination. In the Black Sea, Mediterranean and NE Atlantic, these figures were 79 %, 98 % and 95 %, respectively. Most of the contamination was caused by heavy metals (EEA, 2018d).

Sediments are a sink for many substances. In the Baltic Sea, Black Sea, Mediterranean and NE Atlantic, 77 %, 58 %, 32 % and 43 % of the assessed sediment sites were classified as problem areas in terms of sediment contamination (EEA, 201d). Metals and tributyltin (TBT) are the main causes of contamination.

Mussels and small-sized fish are the typical species used for the assessment of contamination in biota. The integrated assessment showed that problem areas of contamination were found in 89 % of the Baltic Sea assessment sites, 100 % of the Black Sea sites, 89 % of the Mediterranean sites and 92 % of the NE Atlantic sites (EEA, 2018d). In biota, the organobromines and other organohalogens are the substances causing the contamination problems.

The main reasons for the poor condition of the sea areas are the so-called uPBT substances, which are ubiquitous, persistent, bioaccumulating and toxic. By excluding the uPBTs from the analysis, only a few percent of the Europe's coastal seas are disturbed by hazardous substances (EEA, 2018b) and this positive effect is even stronger farther out from the coast. Similarly, the assessment results under the EU WFD showed that the contamination by priority substances may be higher in the inland waters than at sea (EEA, 2018b), where many of the substances have already degraded. This is not the case for uPBTs.

Figure 3.27: Hazardous substances pressure in the marine environment



Notes: The layer combines the integrated state assessment of hazardous substances, locations of ports as well as the coastal EU WFD waterbodies where hazardous substances are identified as the main pressure preventing the good ecological status. **NPA:** non-problem area; **PA**: problem area. See Appendix A for the data layer description.

A factor of uncertainty in the assessment, is in the differences in countries' monitoring efforts; not all the priority substances are monitored, and their spatial resolution may not reach the precision sufficient for an adequate analysis (EEA, 2018d). Good monitoring programmes are likely to capture more harmful substances from the environment, and consequently more likely to reveal contamination problems.

In addition, the EU Priority substances do not include all the contaminants in the marine environment. They are a small subset of the thousands of chemicals in daily use, and, in many cases, restrictions have been in place for decades. More recent concerns, e.g. pharmaceuticals or mixtures of chemicals, are not still reflected in the list of priority substances or contamination assessments.

Contamination in marine regions

In the **Baltic Sea**, the concentrations of most hazardous substances are below the threshold values, but the area is still contaminated by a few uPBT substances (HELCOM, 2018a). The perfluorooctanosulphonate (PFOS), polycyclic aromatic hydrocarbons (PAHs), hexabromocyclododecane (HBCDD), polychlorinated biphenyls (PCBs), dioxins and furans, cadmium and lead indicate no risk for mussels, small fish or humans anywhere in the region. In contrast, polybrominated diphenylethers (PBDE), TBT, cesium-137 and mercury are still above the thresholds in all or most of the monitored sites. The levels are not increasing, except in a few sites, but also the decline is not visible for all the substances (HELCOM, 2018a). In most assessed sites, the concentrations showed no detectable trend.

Mediterranean. The regional sea assessment is limited to heavy metals only and indicates that mercury and lead concentrations in sediments generally exceed the threshold values and cadmium levels exceed the background concentration but not the threshold of adverse effects (UNEP/MAP, 2017). The metal levels are much lower in mussels and fish.

In the NE Atlantic, concentrations of PAHs, PCBs, PBDE, TBT and heavy metals (Cd, Hg, Pb) are declining in fish and mussels (OSPAR, 2017). The levels of almost all substances are below threshold values. The toxic CB-118 is however above the thresholds. Sediment concentrations are higher, and the declining trend is not as coherent as in the biota in the region.

Black Sea. In contrast to the other marine regions, the Black Sea contamination is not predominantly caused by heavy metals but organohalogens (EEA, 2018d).

Contamination of the deep seas

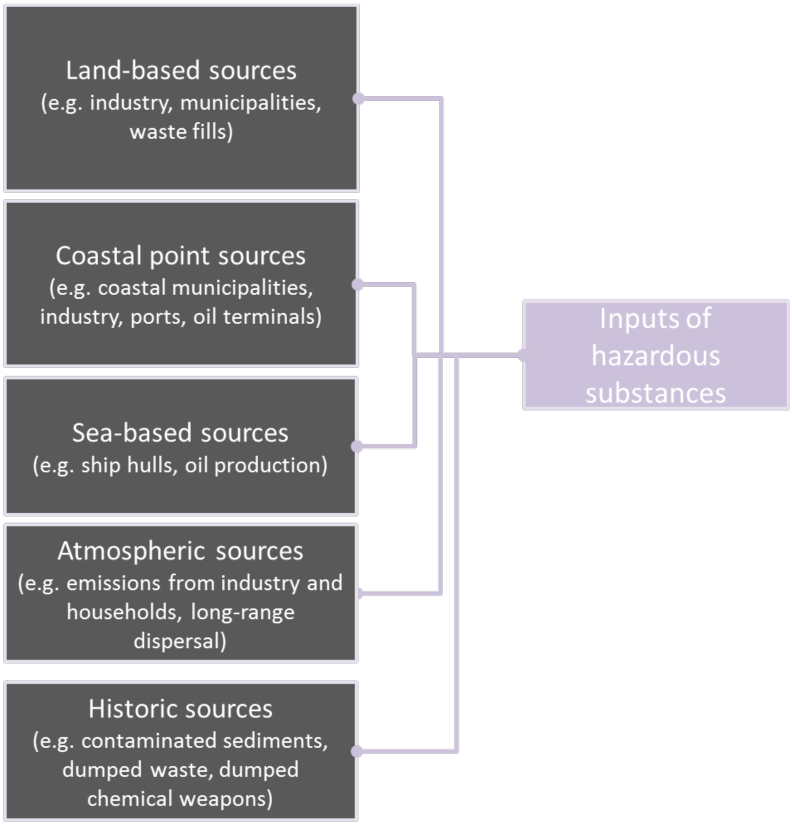
Chemicals are accumulating in deep-sea sediments, benthos and midwater fauna and this environment may be a global sink for persistent semi-volatile contaminants (Froescheis et al., 2000, Looser et al., 2000). Dominant contaminant groups found in the deep sea are persistent organic pollutants (POP), heavy metals (Hg, Cd, Pb, Ni), pesticides, herbicides and pharmaceuticals. Studies have shown that the POP concentrations of DDTs and PCBs declined during the 20th Century, but this was slower or non-existent in the deep sea (Looser et al., 2000). Indeed, a commercially exploited red shrimp (*Aristeus antennatus*) has a higher dioxin content at 2,000 m depth than at a depth of 500 m (Rotllant et al., 2006) and elevated POP levels were found from cephalopods at depths of 1,120–2,980 m (Unger et al., 2008).
Many hazardous substances accumulate in fish and seafood and may become a source of toxic pollutants for higher-level organisms in the food web, including humans (Fréry et al., 2001; Bocio et al., 2007; Cade et al., 2018; Schuetze et al., 2010; von Stackelberg et al., 2017; Budnik and Casteleyn, 2019).

Main activities causing pollution

The main activities leading to failure to achieve good chemical status in the coastal waters are atmospheric deposition and discharges from urban waste water treatment plants on the coast or further in the catchment area (Figure 3.28; EEA, 2018b). Diffuse discharges originating from land-fills, waste stacks, polluted sediments or industrial activities can, however, be significant sources (HELCOM, 2010).
Inputs from urban waste water treatment plants lead to contamination by PAHs, mercury, cadmium, lead and nickel as well as a number of pharmaceuticals (HELCOM, 2018a; EEA, 2018d). Significant levels of some priority substances have built up from historical use, and this legacy pollution may persist long after polluted discharges and inputs have ended.

The burning of fossil fuels and waste leads to the emission of some hazardous substances, which can travel a long way through the atmosphere before being deposited in water. Pesticides used in agriculture have been widely detected in groundwater and surface water. Mining can exert locally significant pressure on the chemical quality of water resources in parts of Europe, particularly with respect to the discharge of heavy metals. Landfill sites and contaminated land from historical industrial and military activities can be a source of pollution of the aquatic environment. Shipping, harbour and port activities, and aquaculture can also lead to the emission of a variety of chemical pollutants.

Figure 3.28: Human activities causing inputs of hazardous substances to sea



3.7 Marine litter

KEY MESSAGES:

- Marine litter pollution is a pervasive, worldwide pressure, present on coastlines, on the sea surface and on the seabed.
- Land-based sources contribute the largest proportion of litter, mostly transported by rivers.
- Main sea-based sources are fishing and shipping. No spatial data was available for distribution analyses.
- Plastic items are the most abundant and damaging component of marine litter that accumulates in the environment due to plastic longevity.
- Impacts of marine litter are harming marine ecosystems, through litter ingestion, entanglement, accelerated invasions of non-indigenous species, and potential toxicity of released chemicals from plastic.

Litter pollution, particularly plastic, is a by-product of industrial production and ends up in the environment as a result of consumer use. Nowadays, the most widely used and produced man-made materials are plastics. After several decades of plastic release into the environment, it has become one of the most significant pollutants worldwide. The World Economic Forum (WEF, 2016) reported that only 14 % of plastic is collected for recycling after use, 54 % is incinerated or landfilled, and a staggering 32 % is released into the environment. Due to durability, low-recycling rates, poor waste management, and maritime use, a significant portion of produced plastic items finds its way to their final destination, seas (Kenyon and Kridler 1969; Werner et al., 2016; Lebreton et al., 2017; Lusher et al., 2017).

Subsequently, plastic has been found everywhere in the oceans, from beaches to the deep-sea trenches (Pham et al., 2014). Degradation of plastic in the deep-sea is additionally hindered, due to diminished mechanical and photolytic forces (Worm et al., 2017).

Litter enters in marine ecosystems from land-based and sea-based sources (Figure 3.29). Most marine litter (80 %) is emitted from land-based sources (UNEP-MAP, 2015) and microplastics from car tyres are estimated to be the main compartment of microliter (Siegfried et al. 2017).

Siegfried et al. (2017) estimated that the annual inputs of microplastics from European rivers is 14.4 kt. The highest share was to the Mediterranean (5.6 kt), followed by the Black Sea (4.1 kt), NE Atlantic (2.7 kt), North Sea (1.1 kt) and the Baltic Sea (0.9 kt).

Once in the sea, marine debris can travel immense distances, transported by currents, jets, and prevailing winds (Andrady, 2015; WWF, 2015). Moreover, plastic materials are also incredibly persistent, especially in the aquatic environments (Worm et al., 2017). Therefore, plastic litter steadily accumulates in high densities and slowly degrades over centuries into smaller particles, called microplastics, which still exert detrimental impacts on their surroundings (Figure 3.30). Eriksen et al. (2014) estimated that over five trillion plastic pieces, weighting > 250,000 t are currently floating in the seas. The estimates for the total amount of all litter in the oceans (floating and also on the seafloor) range from around 150 million tonnes of plastic, with an additional 8 million tonnes added every year (Aliani et al., 2003, ENVI, 2017).

Figure 3.29: Land-based and sea-based activities introducing marine litter

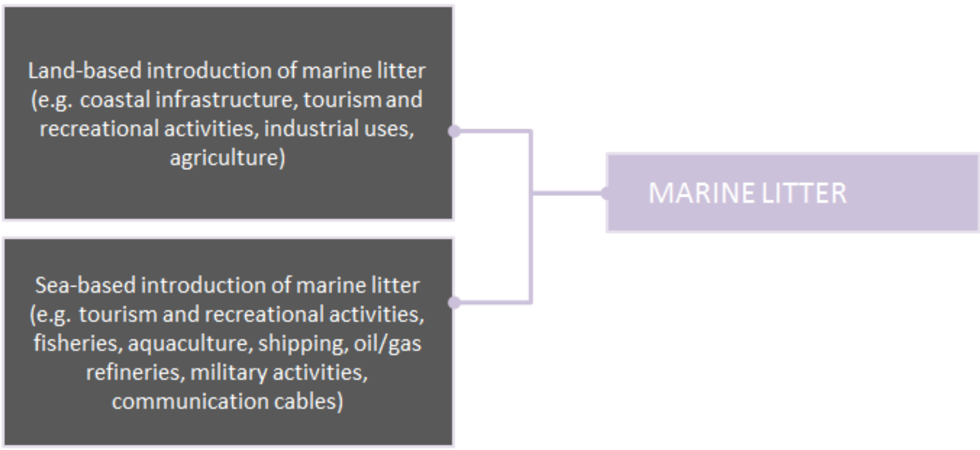
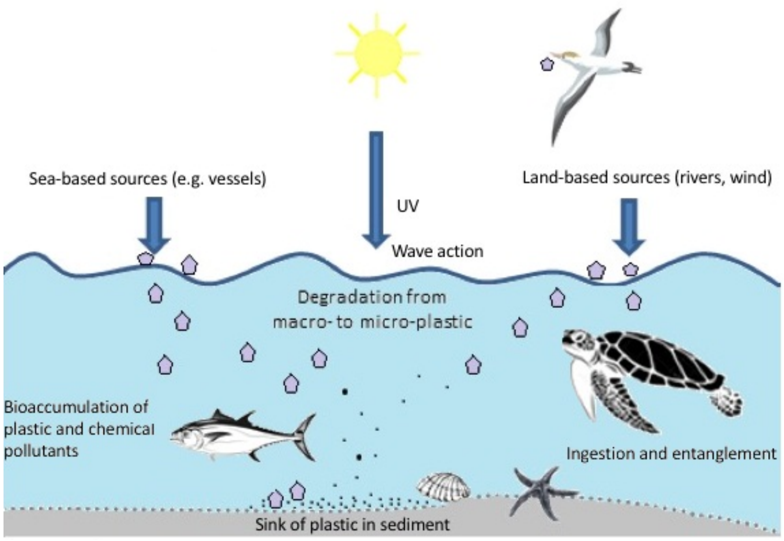
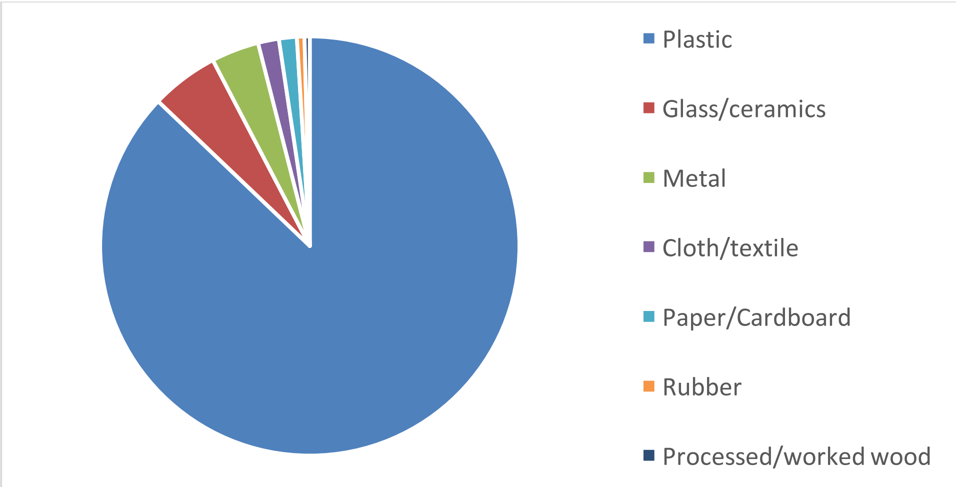


Figure 3.30: Diagram of the degradation pathways of plastic in the sea with ingestion pressure presented



Macro litter on coastlines, i.e. beach litter, is the best-known aspect of marine litter pollution and is now included in obligatory monitoring at national level for all EU countries. The Marine Litter Watch (MLW) activity is one of the initiatives led by the EEA, to reduce litter present in the marine environment. The analyses of collected litter items showed that the top three identified items found on beaches were cigarette butts and filters, plastic pieces, and polystyrene pieces (Figure 3.31). Artificial polymers are by far the most common material, being present in 82 % of collected marine macro litter on European beaches.

Figure 3.31: Distribution of collected litter items by material through Marine Litter Watch activities in the period 2014–2017



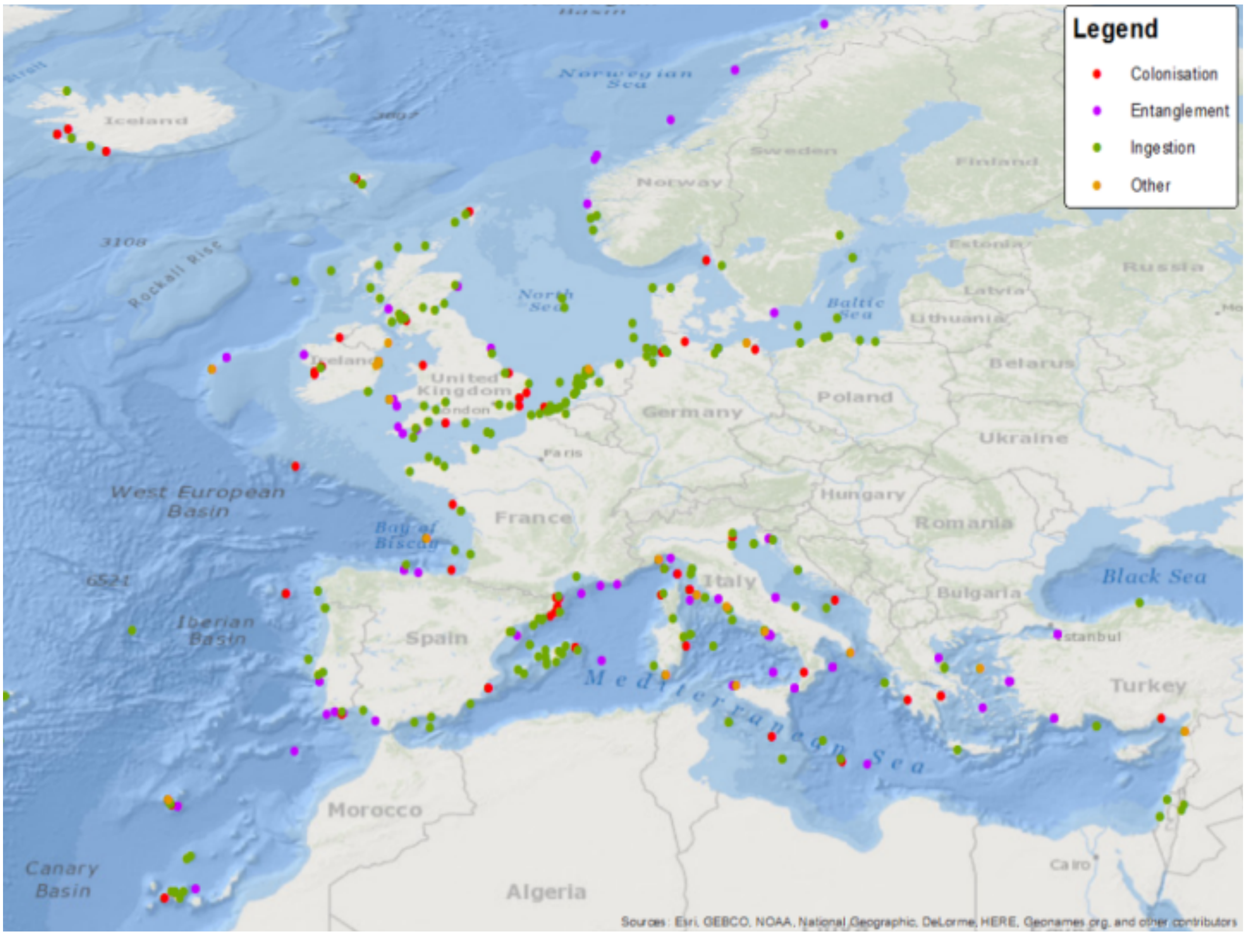
Litter in the deep sea. The most common litter types found on the deep seafloor in the Mediterranean and NE Atlantic are soft plastic (e.g. bags), hard plastic (e.g. bottles, containers), glass and metal (e.g. tins, cans) (Ramirez-Llodra et al., 2011). Surveys in the Mediterranean and Atlantic continental slope and bathyal and abyssal seafloor have shown that litter accumulates even at these depths. For example, two oil drums, a km^{-2} is considered a common density in the Mediterranean deep sea (Ramirez-Llodra et al., 2011). Disposal of radioactive waste took place some decades ago onto the slopes and canyons of the NE Atlantic, and although that has been stopped, the waste drums still exist (Ramirez-Llodra et al., 2011).

Litter pollution causes **harm to the marine ecosystem**. It is assumed that macro- and micro-litter can change the structure and functioning of ecological communities (Eriksson and Burton, 2003). Scientific studies report the interactions of marine organisms with litter and often the consequences are lethal (Figure 3.32).

Entanglement of animals in litter items is mostly caused by discarded fishing gear, also known as “ghost fishing” (Allen et al., 2012; NOAA, 2015). This occurs when discarded or derelict gear continues to catch and trap animals, typically killing them, while also smothering habitats and presenting a hazard to navigation. High entanglement rates are attributed also to differing packaging straps and balloon strings (Gall and Thompson, 2015).

Seabirds, turtles, mammals, and fish, are known to **ingest** marine plastics, mistaking them for food (Foekema et al., 2013). In contrast to entanglement, the ingestion is rarely lethal and more often cause sublethal effects, such as injuries and negatively affects the fitness of organisms (Rochman et al., 2013; Kühn et al., 2015). Solely in the Mediterranean, more than 180 marine species have ingested plastic, with the highest concentrations found in loggerhead sea turtles (*Caretta caretta*; Romeo et al., 2015; UNEP/MAP, 2017). In the NE Atlantic, Northern fulmars (*Fulmarus glacialis*) research also showed that more than half of the birds assessed had ingested plastic (OSPAR, 2017). However, over the last five years no significant increases or decreases in the ingested plastic mass have been observed in the European Atlantic area.

Figure 3.32: Interactions of marine organisms with marine litter, based on literature review (https://litterbase.awi.de)



When plastic particles are ingested worrisome consequences can be anticipated due to the desorption of chemical compounds added in the production process as well as various organic pollutants adsorbed from the environment to the items, that can be released (Engler, 2012; Lusher et al., 2013; Lusher et al., 2017; Bakir et al., 2014). Bioaccumulation and biomagnification processes escalate the toxicity effects, and spread through the food chains and webs (Eriksson and Burton, 2003; Lusher et al., 2015).

Litter acts also as **a transfer vector** for biota, potentially aggravating the invasive NIS crisis (Kirstein et al., 2016; Werner et al., 2016). Marine litter movements have been linked with the dispersion patterns of non-native species (Reisser et al., 2014). Zettler et al. (2013) proved that microbial communities on marine litter consistently differ from the surrounding environments and named these new habitats as the ‘plastisphere’.

3.8 Underwater noise and other forms of energy input

KEY MESSAGES:

- Human-induced underwater noise is one of the forms of energy that causes stress and, in extreme events, harm to marine animals.
- Anthropogenic sounds may be long lasting (continuous) or of a short duration (impulsive) affecting organisms in different ways.
- Maritime traffic presents the largest anthropogenic contribution of low frequency continuous noise in oceans and seas.
- Main sources of impulsive noise are pile driving (construction), seismic exploration with airguns, explosions, and sonar systems.
- Various levels of pressure from increased continuous and impulsive underwater noise emissions are present in the majority of Europe's seas.
- Other forms of energy – electromagnetism, thermal pollution and artificial light are local pressures and their effects depend on local ecosystem characteristics.

The MSFD addresses several forms of energy input to the marine environment, namely underwater noise, magnetic, electromagnetic radiation, heat and light. Currently only underwater noise, caused by anthropogenic sound inputs, is addressed at EU level.

Underwater noise

The underwater environment is filled with biotic and abiotic sounds, many of which can be important for the survival and reproduction of marine fauna. Underwater sound spreads five times faster than sound in the air and is an excellent tool for marine organisms for their communication, navigation and to follow their prey.

Over the last century, human activities in and near the water have increasingly added artificial sounds to this environment and has changed the 'soundscape' for marine fauna. Anthropogenic sounds may be long lasting (continuous noise) or of short duration (impulsive noise) affecting organisms in different ways. The sound effects are divided to short time-scale effects (i.e. acute effects) or long time-scale effects (chronic effects) (Tasker et al., 2010). In this chapter underwater noise refers to anthropogenic sound.

Continuous underwater noise is found in the entire European marine area and mainly produced by maritime traffic (Figure 3.33; Figure 3.34). As no thresholds for pressure have been agreed yet, even areas of low or infrequent maritime traffic are included in this assessment. About 9 % of Europe' seas are estimated to be exposed to very high-density traffic and ~ 11 % of the area of Europe's seas is estimated as not have shipping traffic (Figure 3.34). The NE Atlantic has the widest non-trafficked area (14 % of the sea area), whilst the Mediterranean Sea has only 1 % of the area as non-trafficked.

Figure 3.33: Activities producing underwater noise

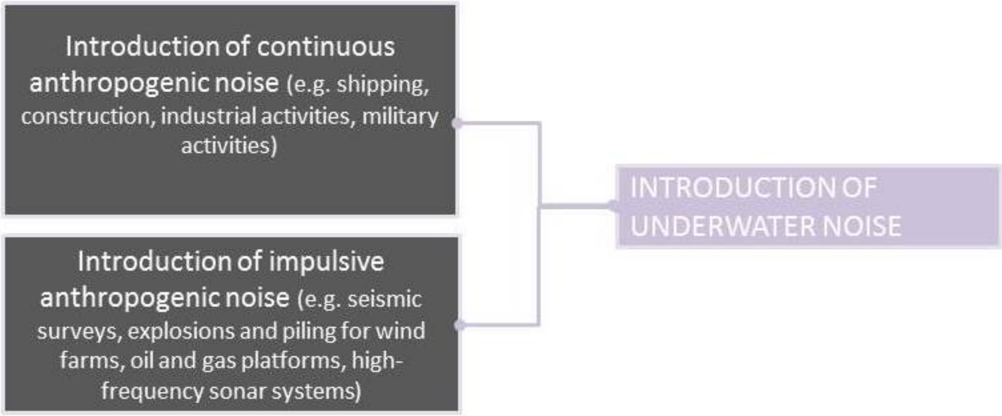
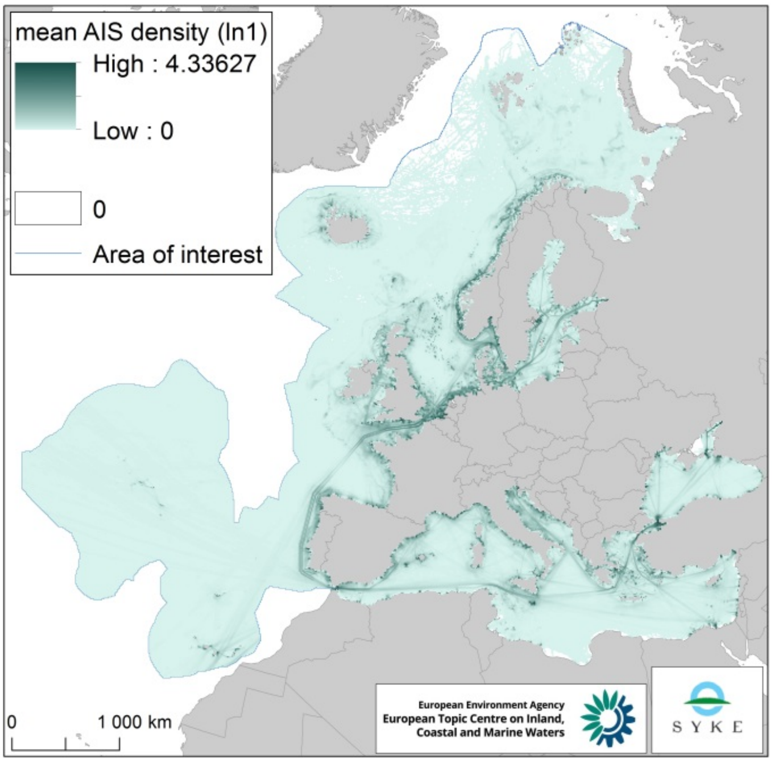


Figure 3.34: Shipping density (log-transformed) as a representation of distribution of continuous underwater noise. See Appendix A for data description.

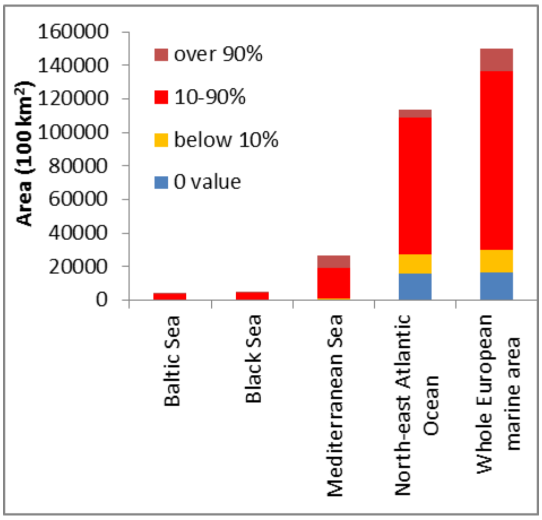


Note: AIS – Automatic Identification System is an automatic, vessels tracking system.

Sources of continuous noise

Continuous noise can be defined as a background noise without distinguishable sources (Tasker et al., 2010). Maritime traffic presents the largest anthropogenic contribution of low frequency continuous noise in seas and oceans. Increases in commercial shipping are believed to account for the observed low-frequency ambient noise increase (McDonald et al., 2006). In addition, small tourist and leisure crafts can be a source of high levels of continuous underwater noise, especially at tourist locations during tourist season. Correlations between maritime traffic and noise measurements, for example in the Baltic Sea (HELCOM, 2018d), have shown that anthropogenic noise maps can be drawn on the basis of shipping data (Figure 3.34). Aggregated data show, that the majority of Europe's seas are exposed to underwater noise emissions from shipping (Figure 3.35). Knowledge about large scale effects of underwater noise on marine animals is still incomplete, therefore threshold values are still under development.

Figure 3.35: Distribution of shipping intensity in the European marine areas (e.g. areas of highest and lowest, 10 % of the total European shipping intensity)

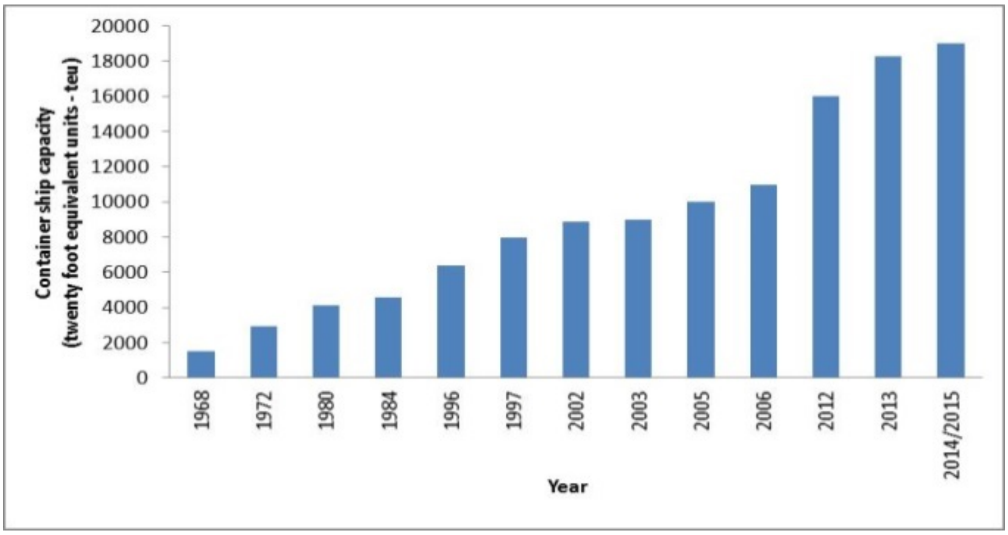


Trends of shipping causing continuous noise

The number of commercial vessels in the world's oceans approximately doubled over the past 50 years and the gross tonnage quadrupled, with a corresponding increase in horsepower (Berns et al., 2015). This is also visible in the EU trends since the late 1990s when vessel gross tonnage and the amount of goods transported have been growing in the years 2009–2016, but have not reached the record of the years before the financial crisis in the late 2000s. During the same period, the number of vessels has decreased by 10 % in the main EU ports (Figure 3.36).

Overall maritime throughput in the European Union has been growing in past years but has not reached the pre-recession levels. The outlook is however increasing: The European maritime freight traffic is expected to increase by 74–82 % between 2010–2030 and container port capacity will follow closely by a 42–50 % increase (OECD, 2016). The number of vessels in the main European ports is predicted to continue its decrease while overall ship size will still increase (UNCTAD, 2015). Studies indicate that larger vessels emit higher values of underwater noise (e.g. McKenna et al., 2013). Thus, based on the available information on the shipping sector, assessment of the pressure trend is not straightforward.

Figure 3.36: Increase in container carrying capacity from 1968 to 2015



Source: Berns et al. (2015)

In order to assess trends in the noise directly, long-term monitoring is needed, but that is operational only in a few sites and in the Baltic Sea. By coupling the monitoring data with modelling, the effects of physical and geological factors can be included into the sound distribution estimates (Borsani et al., 2015; Farcas et al., 2016). As an example, continuous underwater noise levels have been monitored by hydrophones and modelled in the Baltic Sea.

Sources of impulsive noise

Impulsive sounds are typically brief with a rapid rise time, i.e. a great change in amplitude over a short period of time. The main anthropogenic sources of impulsive underwater noise are impact pile driving for inshore and offshore construction, seismic exploration with airguns, explosions, and sonar systems (Figure 3.37).

Data collected on impulse noise sources enable the description of the spatial and temporal distribution of impulsive noise pressures and provide support to EU Member States in setting targets for managing impulsive noise radiating activities. A register for the NE Atlantic and Baltic Sea has been established at ICES (https://underwaternoise.ices.dk/map.aspx). A register for the Mediterranean and the Black Sea has been established at ACCOBAMS (http://accobams.noiseregister.org/). Data collected from the registers enables the assessment of pulse block days, during which activities emit impulsive noise (Figure 3.37).

Impulsive noise is present in 32 % of the Baltic Sea, 18 % of the Mediterranean Sea and 5 % of the NE Atlantic (Figures 3.37 and 3.38). The pressure was relatively more spread in the shelf area than elsewhere. No data was available from the Black Sea, Arctic or the Macaronesian area.

Figure 3.37: Impulsive underwater noise in Europe's seas. See Appendix A for data description.

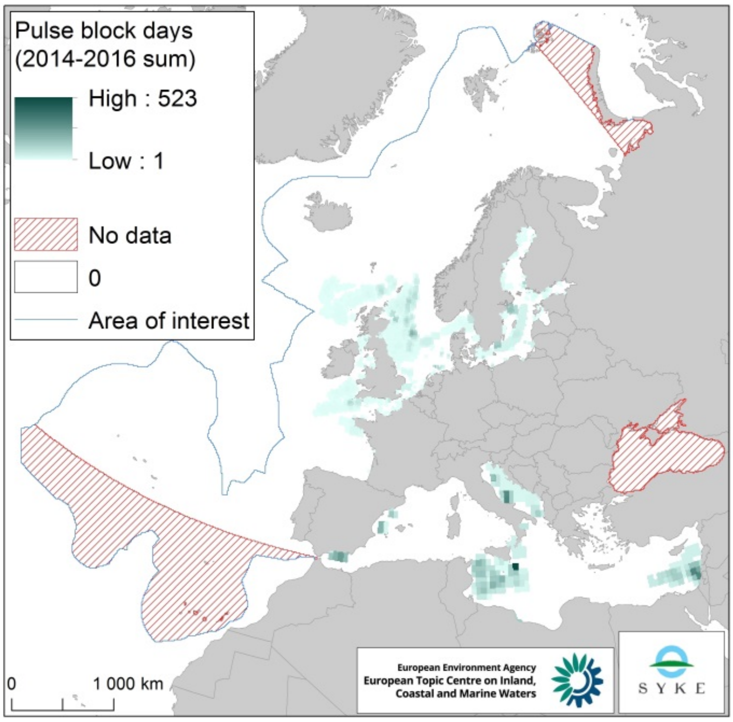
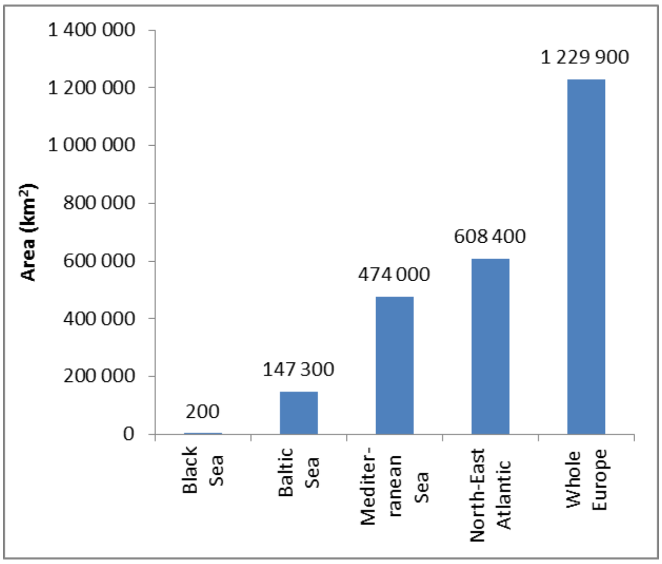


Figure 3.38: Area of impulsive underwater noise in Europe's seas



Trends of activities causing impulsive underwater noise

Since the available information on monitoring of impulsive noise sources remains limited, the trend of this pressure can be assessed based on the development of human activities as drivers. Among them, off-shore wind energy construction is one of main drivers of impulsive noise because pile-driving is the main building technique used. This sector has experienced exponential growth in European seas after 2000 and will continue to grow (WindEurope, 2018). Wind farms will be constructed also in deeper waters and at larger distances to shore resulting in spatially extending pressures. The pressure could however be minimized with using alternative construction methods or mitigation measures (Koschinski and Lüdemann, 2013).

Impacts of noise on marine life

Anthropogenic underwater noise is recognized as a world-wide problem, and recent studies have shown a broad range of negative effects in a variety of marine species (Andre et al., 2011; Williams et al., 2015). Intense **impulse noise** is more likely to have acute impacts including temporary or permanent injury to auditory systems or even strandings to shore (Tasker et al., 2010). By contrast, **continuous noise** is more likely to produce chronic effects such as masking of communication and stress (Brumm, 2013).

Marine mammals, especially cetaceans are highly vocal. They use sound for communication, finding food, reproduction (mating), detection of predators or hazards and navigation (Weilgart, 2007). Studies have shown that anthropogenic noise can mask signals important to marine mammals such as communication sounds, echolocation, predator and prey sounds (Slabbekoorn et al., 2010; Erbe, 2012). Acute noise exposure can also result in a loss of hearing sensitivity. If hearing returns to normal after some time, the effect is temporary and considered as auditory fatigue, whereas a permanent effect is considered as an injury (Erbe, 2012).

Other observed effects of noise on marine mammals include changes in vocalization, stress, changes in respiration, increased swimming speed, orientation away from the sound source, sudden and longer dives, shifts in migration paths, strandings, changes in foraging and breeding behaviour, as well as physiological damage (in air cavities and cochleae in the mammal ear, and tissue damage from air bubble growth) and mortality (EIA, 1998; NRC, 2000; Weilgart, 2007; Erbe, 2012). Observed reactions to noise in marine mammals could theoretically result in impacts such as decreased foraging efficiency, higher energetic demands, less group cohesion, higher predation, decreased mating and reproduction (Myrberg, 1990; Richardson et al., 1995; Würsig and Richardson, 2000; Williams et al., 2002; Weilgart, 2007).

Fish. Very loud sounds of relatively short exposure, such as those produced during pile driving, could harm nearby fish. More moderate underwater noises of a longer duration, such as those produced by vessels, could potentially impact much larger areas, and involve much larger numbers of fish (Slabbekoorn, et al., 2010).

Chronic exposure to anthropogenic noise can affect growth and reproductive processes of fishes (disrupted mating, lower egg viability, reduced larval growth rates) (Banner et al., 1973; Pickering, 1993; Verzijden et al., 2010; Vasconcelos et al., 2007; Popper et al., 2009; Codarin et al., 2009; Brumm, 2013), increase secretion of the stress hormone cortisol (Smith et al., 2004; Wysocki et al., 2006, 2007), increased motility (Buscaino et al., 2010), cause short or long term displacement from locations (Engås et al., 1996), damage tissue and cause hearing loss or result in death (Popper et al., 2009; Slabbekoorn et al., 2010).

Other taxa. Vertebrates like birds and turtles have air-filled cavities which are vulnerable to damage. Effects from anthropogenic noise on birds may depend on how often and deeply seabird species dive, and their tendency to be disturbed by noise (Blank et al., 2000). Continued exposure to high levels of anthropogenic noise in sea turtle habitats could affect sea turtle behaviour and ecology (Samuel et al., 2005). Anthropogenic noise, especially of a continuous nature, has the potential to interfere with the settlement and recruitment processes of crab larvae, which are using ambient underwater sound to locate and settle into suitable habitats (Stanley et al., 2012).

Inputs of electromagnetism

Electromagnetic fields at biologically relevant levels are generated by operational transmission cables (Thomsen et al., 2015). Electric fields increase in strength as voltage increases (Gill and Taylor, 2001). Magnetic fields are generated by the flow of current and increase in strength as the current increases. The strength may reach the multiple of the natural terrestrial magnetic field. Directly generated electric fields are controllable by adequate shielding, however, induced electric fields generated by the magnetic field will occur. Because the strength of both magnetic and electric fields rapidly declines as a function of the distance from the cable, an additional reduction of the exposure of marine species to electromagnetic fields can be achieved by cable burial (Merk, 2009).

Magnetic fields generated by cables may impair the orientation of fish (Gill et al., 2012) and marine mammals and affect their migratory behaviour (Klaustrup, 2006; Merk, 2009). Both, telecommunication and power cables lead to seabed disturbance and associated impacts of damage, displacement or disturbance of flora and fauna, increased turbidity, release of contaminants and alteration of sediments (see Section 3.7).

Thermal pollution

Marine waters are used to cool power plants and the warmed water is discharged back into the sea. The effect area and energy of this waste heat depends on the size of the plant and discharge volume (IAEA, 1975). A nuclear power plant annually discharging 56 PJ of heat into the sea with a flow rate of 44 $m^3 s^{-1}$ causes a temperature increase of 8–12°C (Ilus, 2009). Onshore nuclear power plants have warm-water outflows affecting coastal waters typically 3-8 kilometres from the site. The effects are largely dependent on the local characteristics, i.e. exposure to waves, tides, depth, upwelling, etc. In general, the increased water temperatures enhance pelagic and benthic primary and secondary production and alter the natural benthic communities and habitats of the impact area (Ilus, 2009).

Thermal radiation from submarine cables has become an issue of increasing concern. When electric energy is transported, a certain amount gets lost as heat, leading to an increased temperature of the cable surface and subsequent warming of the surrounding environment. The temperature increase of the upper layer of the seabed inhabited by most of the benthos depends, amongst other factors, on the burial depth of the cable. The temperature rise is reduced by increasing the burial depth of cables (Merk, 2009).

Artificial light

Night-time artificial lighting from coastal developments, shipping and offshore infrastructure has not been studied widely. It is known to disrupt navigation, increase mortality, alter spatial and temporal activity patterns of marine birds, turtles and fish (Witherington et al., 1991; Bourgeois et al., 2009; Merkel, 2010; Becker et al., 2012), and alter the composition of epifaunal marine invertebrate communities (Davies et al., 2014, 2015). Davies et al. (2014) estimated that 54 % of Europe's coastline is affected by artificial light; this is more than anywhere else in the world. While the above-surface effects can be wide, underwater effects are likely limited to local habitats.

3.9 Microbial pathogens

KEY MESSAGES:

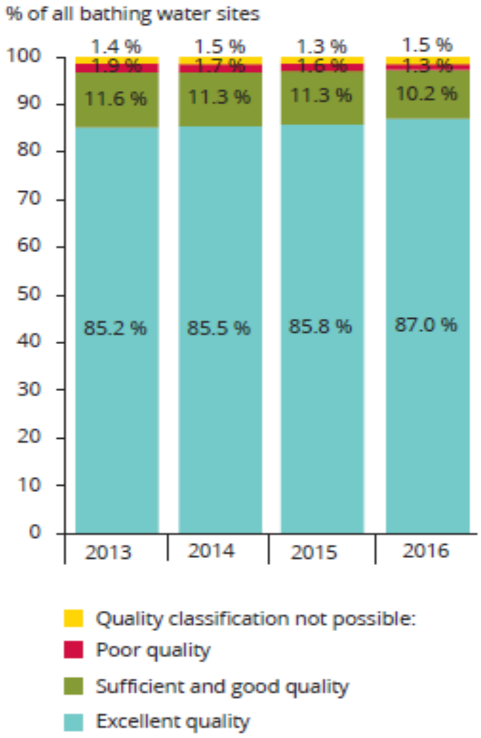
- Microbial pathogens are introduced to the marine environment from municipal sewage, ships, bathing sites, aquaculture and animal husbandry.
- The risk for microbial pathogens exists in approximately 2–8 % of Europe's coastal waters.

Microorganisms are a vital component of marine ecosystems, decomposing organic material into nutrients. Most microorganisms are beneficial and pose little or no health risk, but some of them can be harmful to marine ecosystems, incl. humans. Those are known as pathogens.

Pathogenic microorganisms are composed of various disease-causing aquatic organisms, such as bacteria, viruses, protozoa, and fungi (Alberts et al., 2002). The United Nations have recognized the transfer of harmful organisms and pathogens across natural barriers as one of the four greatest pressures to the world's oceans.

The current monitoring and systematic examination of pathogens in marine waters is implemented under the Bathing Water Directive (2006/7/EC). Data reported under this directive showed an increasing trend of the proportion of coastal bathing water sites achieving excellent or sufficient and good quality across the European seas (Figure 3.39).

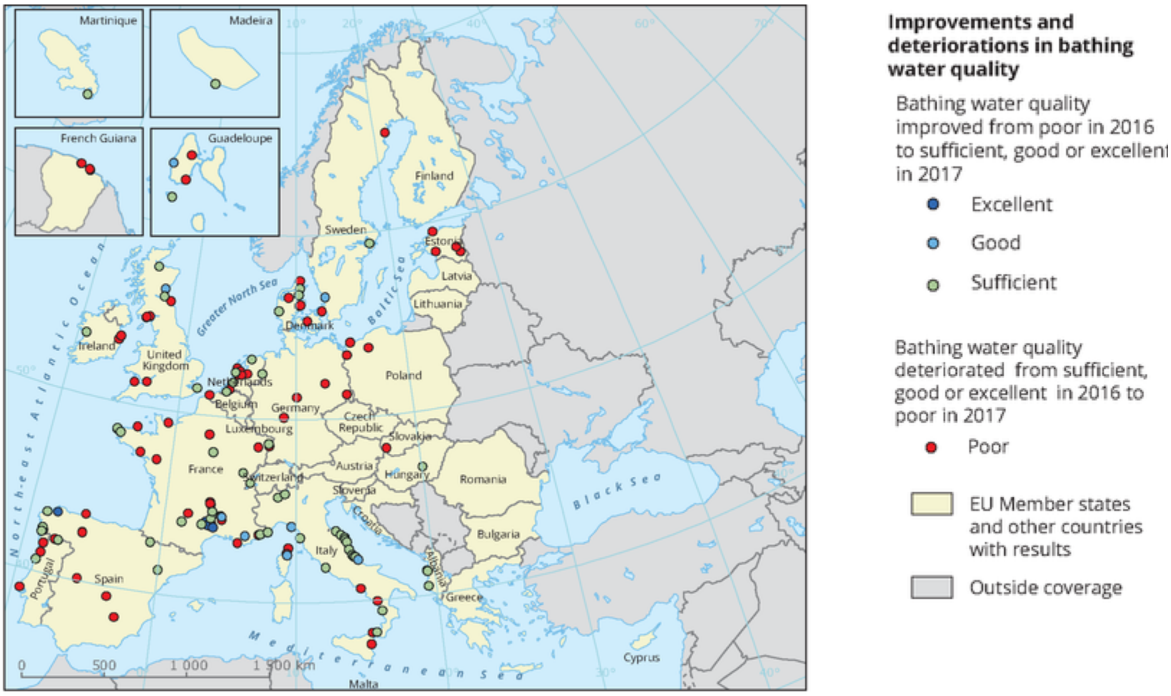
Figure 3.39: Quality of coastal bathing waters by pathogen indicators in the EU (EEA, 2019k)



The obtained results demonstrated primarily progress in the more efficient wastewater treatment and the reduction in pollution from farms. The potential faecal pollution was measured by concentrations of two indicator pathogen species *Enterococcus faecalis / faecium* and the bacteria *Escherichia coli*.

There has been a recent decrease in bathing water quality between 2015 and 2016 in the Mediterranean Sea and an increased water quality at the same time in NE Atlantic Ocean (Figure 3.40).

Figure 3.40: Improvements and deteriorations in bathing water quality (EEA, 2019k)

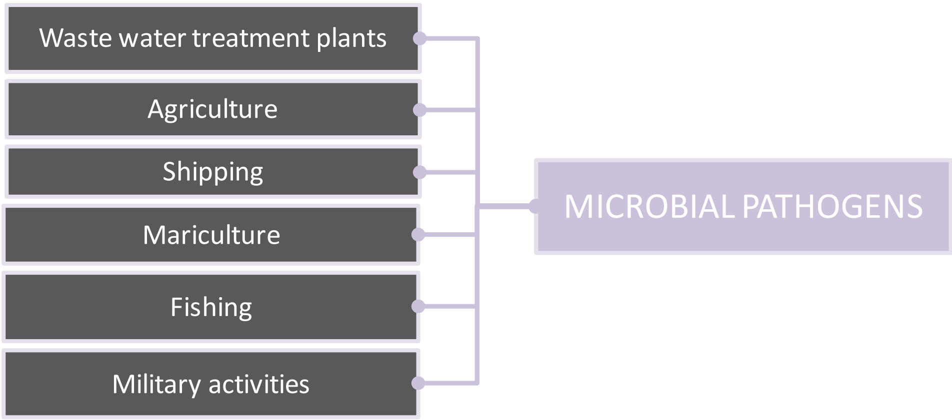


Sources: National boundaries from EEA Bathing water data and coordinates by reporting countries authorities.

Sources of microbial pathogens

The major source and transmission mechanism of microbial pathogens to the marine environment is sewage, as the origin of most marine microbial pathogens is faeces, with only a few bacterial pathogens able to grow in the marine coastal environment (Figure 3.41). The load of microbial pathogens decreases with the improved treatment of sewage (Brettar et al., 2007). Conversely, diffuse sources are often intermittent in nature and include runoff from urban and agricultural areas (Hernández-Terrones et al., 2015; Staehr et al., 2018), leaking septic systems and sewerage lines, combined sewer overflows, and atmospheric deposition of aerosols (Stewart et al., 2008). Additionally, industrial waste, aquaculture, wildlife excrement (Defoirdt, 2016; Malham et al., 2014), tourism, fishing, and even "bather-shedding" (Malham et al., 2014) have been implicated as considerable sources of pathogenic organisms in the marine realm.

Figure 3.40: Activities producing microbial pathogens on Europe's seas



Water quality can also deteriorate as a consequence of heavy rains and floods, which increase the flushing out of untreated or not efficiently treated sewage into surface waters (Hernández-Terrones et al., 2015). Therefore, the source of pathogens in coastal waters can be contaminated rivers and groundwater.

At sea, maritime transport (e.g. ballast waters and sewage) can be an important source (Peperzak, 2005; Çiftçi Türetken and Altuğ, 2016). With increasing trends of shipping in European seas, the concern for the introduction of potential pathogens is also increasing. Globally, 4 billion metric tons of ballast water are annually discharged (Tsolaki and Diamadopoulos, 2010). Consequently, 7,000 species among microorganisms, plants, and animals can be transferred among sea regions. For this reason, ports are considered as an important potential hotspot for the introduction of harmful and pathogenic organisms. Sewage outflows are also allowed outside coastal waters, unless specifically agreed within the IMO, as in the Baltic Sea.

Survival of microbial pathogens is relatively poor in marine and transitional waters, depending on their physiological state and environmental factors, such as solar radiation, salinity, temperature, organic matter availability, and particle load (Brettar et al., 2007; Stewart et al., 2008; Caruso et al., 2015). All these factors can be strongly influenced by human activities. For example, higher levels of phosphorous and nitrogen, and increased water temperature can significantly support bacterial growth and multiplication (Degerman et al., 2013).

Some bacteria can enter a hibernation state, while others protect themselves from hostile environments by forming bio-films, which are also implicated in biofouling, biocorrosion and the persistence and transmission of harmful pathogenic microorganisms (Dang and Lovell, 2016). Pathogens often accumulate in great concentrations in sediments; concentrations of up to 10,000 times higher than in the surrounding water column (Caruso et al., 2015; Malham et al., 2014). Another accumulation is in so-called flocs (suspended sediment particles), which as a mixture of organic matter and minerals offer protection from a range of biotic and abiotic stressors, while also providing nutrients for population growth. Remobilisation of sediments can cause pulses of pathogenic contamination long after the initial contamination even occurred (Malham et al., 2014).

Impacts of microbial pathogens on marine life

Microbial pathogens can cause human diseases, such as diarrhoea, gastroenteritis, and cholera, or have socio-economical effects such as reduced aquaculture yields. A vast majority of pathogens also have the potential to cause ecosystem effects in marine transitional waters (estuaries, lagoons) and coastal waters (Hernández-Terrones et al., 2015).

The resulting marine diseases can decimate marine populations, especially seagrasses, fish and seals; the outbreaks are particularly problematic when they affect or remove keystone predators or/and foundational species, which consequently disrupt ecosystem function and can shift the ecosystem into a novel state (Groner et al., 2016). While some seagrasses are effective as filters of pathogens and can reduce their concentrations in adjacent waters by as much as 50 % (Lamb et al., 2017), deleterious effects on some of the key marine assemblages are still being reported. *Serratia marcescens*, for example, is linked to the decline of two dominant reef-building corals and a subsequent ecological phase shift from coral to algal-dominated reefs (Lamb et al., 2017). Such disease outbreaks can further alter susceptibility of ecosystems by masking other types of disturbance events, since even after the outbreak event, parasites can influence the process of succession and consequently influence the ecosystem stability (Preston et al., 2016).

The recently discovered rapid emergence of antibiotic resistance demonstrated the importance of horizontal gene transfer to bacterial evolution and produced the idea of »gene pollution«. The introduction of often NIS enteric bacteria into marine environments can introduce genetic elements and virulence traits with the potential to affect the diversity and evolution of native microbial communities (Power et al., 2016).

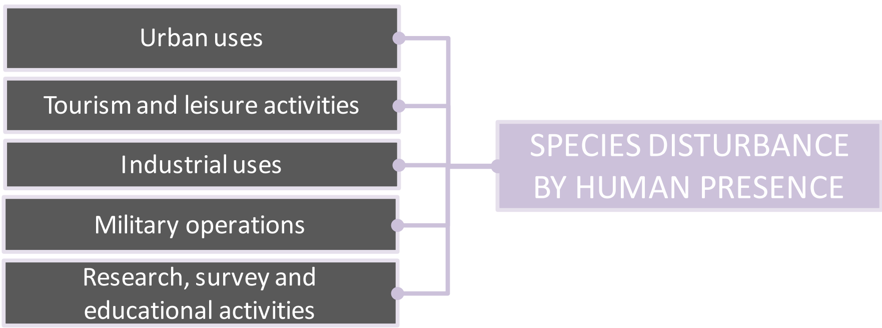
3.10 Species disturbance due to human presence

KEY MESSAGES:

- In nearly 31 % of Europe's coasts human presence disturbs sensitive marine species. The pressure is highest in the Baltic Sea (40 %) and Mediterranean (38 %).
- As the tourism sector is increasing, sensitive marine species face changes in living conditions due to fragmentation and loss of natural habitats.

Human presence and ecotourism have harmful effects on sensitive species and habitats, if the volumes are too high (Griffin et al., 2017). Such effects have been shown for the breeding areas of turtles, pelicans, terns, gulls and cormorants, and suspected for some marine mammals (Buxton et al., 2017; Bearzi, 2017; Machernis et al., 2018).

Figure 3.42: Activities, causing species disturbance



Many Europeans live by the coast. The share of the population within 5 km from the sea vary between 6 % (Belgium) and 98 % (Malta) (median 35 %) (Eurostat, 2013). The high human density near the sea is related to urbanisation, tourism, industrial use, military operations and research (Figure 3.42). Construction in coastal areas cause artificialisation of the coastline and soil sealing on land and natural seafloor loss. These changes influence some marine species – for instance their distribution, density or reproduction – either directly (i.e. physical or visual contact) or indirectly (i.e. altering the habitats, food availability, etc.). Not all the marine species are impacted from urbanization or human presence, but evidence shows that marine mammals, turtles and some sensitive seabird species are disturbed.

About 31 % of Europe's coastal strip (0-10 km) is potentially disturbed by human presence (Figure 3.43). This is in line with the studies showing that most of the human population is living near the coast. This pressure was most extensive in the Baltic and the Mediterranean (40 and 38 %, respectively) but also present in the Black Sea (22 %) and NE Atlantic (26 %).

More than 130 million people live on a permanent basis along the Mediterranean coastline, this figure doubling during the summer tourist season (EEA, 2006). Furthermore, the number of tourists during peak season has been predicted to increase in all the Mediterranean countries by 2025 (Figure 3.43). In contrast, the Baltic coastal population is only about 15 million people (10 km coastal strip; Sweizer et al., 1996) and there are large differences between the densely populated southern Baltic and the sparsely populated northern Baltic. Nonetheless, even there the numbers multiply in the tourism season or when citizens visit and stay at their summer houses.

Figure 3.43: Species disturbance by human presence near the shore. See Appendix A for data description.

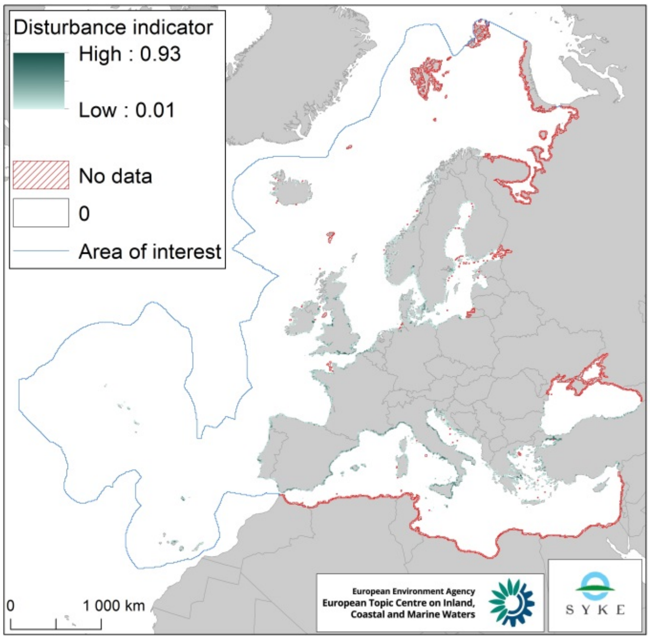
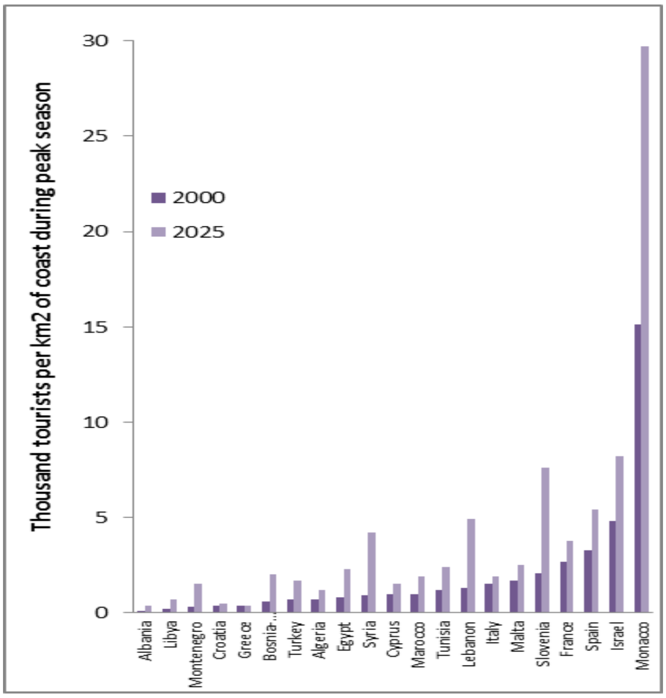


Figure 3.44 Number of tourists in the Mediterranean coast in 2000 and predicted for 2025. Redrawn from: UNEP/MAP, 2012



Tourism and recreational use have been identified as a major threat to wildlife and environment (Davenport and Davenport, 2006). Europe was the most frequently visited region in the world in 2016, accounting for close to half (49.8 %) of the 1.24 billion international tourist arrivals (UNWTO, 2017). Almost half (47.4 %) of the total nights spent in the EU-28 tourist accommodation establishments in 2014 were in coastal areas, particularly the Canary Islands and the Mediterranean coast (Eurostat, 2017h). Within the Mediterranean, the Eurostat tourism pressure indicators showed that the Greek archipelago and Balearic Islands peaked in terms of overnights and tourism density. In the EU Black Sea coastline, there are almost 40 % less tourist accommodation facilities than in the Mediterranean's coastal region (Eurostat, 2011).

Sensitivity of wildlife

Seabirds are often considered sensitive to human disturbance, but this pressure evidently affects the species differently. Colonial seabirds, such as terns, cormorants and pelicans are sensitive to human approach, whereas the Mediterranean storm petrel (*Hydrobates pelagicus melitensis*), for example, seems not to be disturbed by tourist visits by boats to the breeding caves (Soldatini et al., 2015). Such results are supported by a review of colonial seabirds' sensitivity to disturbance (Carney and Sydeman, 1999). The other extremes are breeding pelicans which are highly disturbed by low-flying aircrafts and ecotourism; fleeing from their nests provides predation opportunities for gulls and causes a great decline in reproductive success. The red list of European birds also listed human disturbance as a particular threat to a set of endangered seabirds (BirdLife International, 2015).

Arctic island-breeding terns, gulls, jaegers and non-nesting common eiders lift off their nests when disturbed by approaching aircraft (0.5–1 km distance) or by humans approaching on foot (50–150 m), whereas nesting common eiders and long-tailed ducks were not sensitive to human approach (Mallory, 2016). Neither terns, gulls, common eiders nor long-tailed ducks show any decline in reproductive success after human disturbance (Mallory, 2016). Another review reported that 86 % of bird studies in California detected adverse effects from human disturbance on seabirds (Borgmann, 2011). Although most of the reported disturbances were flushing and behavioural changes, also decreased reproductive success or feeding activity were reported.

At sea, shipping clearly affects offshore species' spatial patterns. In the North Sea, red-throated and black-throated loons (*Gavia stellata; G. arctica*) avoid shipping lanes (Schwemmer et al., 2011). The study also showed that flush distances from ships vary between 200–800 m for common eider (*Somateria mollissima*), long-tailed duck (*Clangula hyemalis*), common scoter (*Melanitta nigra*) and white-winged scoter (*M. fusca*). Recreational boating activities in the foraging grounds of the European shag (*Phalacrocorax aristotelis*) significantly changed the foraging activity and spatial use of the foraging grounds in the Atlantic, NW Spain (Velando and Munilla, 2011).

Energy production structures – wind farms and tidal and wave energy devices – cause collisions with seabirds. Vulnerability studies have suggested that auks, cormorants, shags and divers may be sensitive to tidal and wave energy production, whereas more species (e.g. large gulls and northern gannets) may be more sensitive to wind energy production (Furness et al., 2012; Furness and Wade, 2012).

Coastal development, extensive urbanization of the coastline, especially in areas with sandy beaches, and tourism have severe adverse effects on the nesting of the European loggerhead (*Caretta caretta*) and green turtles (*Chelonia mydas*) (Kasparek et al., 2001; Margaritoulis et al., 2003). Similarly, tourism has played a strong role in the severe decline and local extinctions of the monk seal (*Monachus monachus*) and the threat is still severe as their habitats are in decline (Johnson and Lavigne, 1999). The threat is not only on the beaches but also caused by leisure boating and diving in more isolated areas.

Whale-watching is a form of ecotourism which has also received criticism for its observed adverse effects on whales and other marine mammals (Cressey, 2014). The number of whale-watchers has increased from 4 million in 13 countries in 1991 to 13 million in 119 countries in 2008. In the Atlantic islands, the number amounts to 1.7 million whale-watchers; the majority in Spain (Hoyt, 2005). Without good management, the activity has been shown to repel the animals from their preferred habitats and, hence, affect their nutritional and reproductive condition (Lusseau et al., 2006).

Physical trampling on intertidal habitats has been shown to cause significant reduction of key species (bivalves, mussels, crustaceans, limpets, gastropods and macroalgae) in mudflats (Rossi et al., 2007), seagrass meadows (Garmeania et al., 2017), and rocky shores (Castilla, 1999; Casu et al., 2006; Micheli et al., 2016). Similarly, underwater habitats are altered by small-scale dredging in marinas and private piers (Sandström et al., 2005).

3.11 Pressures from climate change

KEY MESSAGES:

- Climate change poses changes in the physical properties of marine waters resulting in cascade effects on any marine ecosystem.
- Sea level has already risen by about 8 cm in two decades.
- Sea surface temperature has risen in over 85 % of the Black Sea, Mediterranean and NE Atlantic Sea areas and in 64 % of the Baltic Sea area.
- Based on the projections these changes will not subside in the future.
- Ocean warming and acidification, loss of oxygen and changes in nutrient supplies, are affecting the distribution and abundance of marine life.
- Under the influence of climate change, the marine ecosystems become more vulnerable to other anthropogenic pressures.

Global climate change is happening, and its effects are manifesting in European seas. Climate change can be induced by natural and anthropogenic forcing. Nowadays, anthropogenic emissions of greenhouse gases (GHG) into the atmosphere are the most important driver of climate change. Most emissions are released by the burning of fossil fuels, deforestation, agricultural practices, land-use, and forest management practice (IPCC, 2013; EEA, 2017c).

The global ocean acts as a climate regulator and buffer, capturing 28 % of anthropogenic CO_2 emissions since the 1750s and absorbing 93 % of the Earth's additional heat since the 1970s (Gattuso et al., 2015).

Physical and chemical properties of marine waters are changing due to climate change. Among them the most important are altered sea temperature (SST), melting of sea ice, OA, SLR, and changes in salinity (Nagelkerken and Munday, 2016).

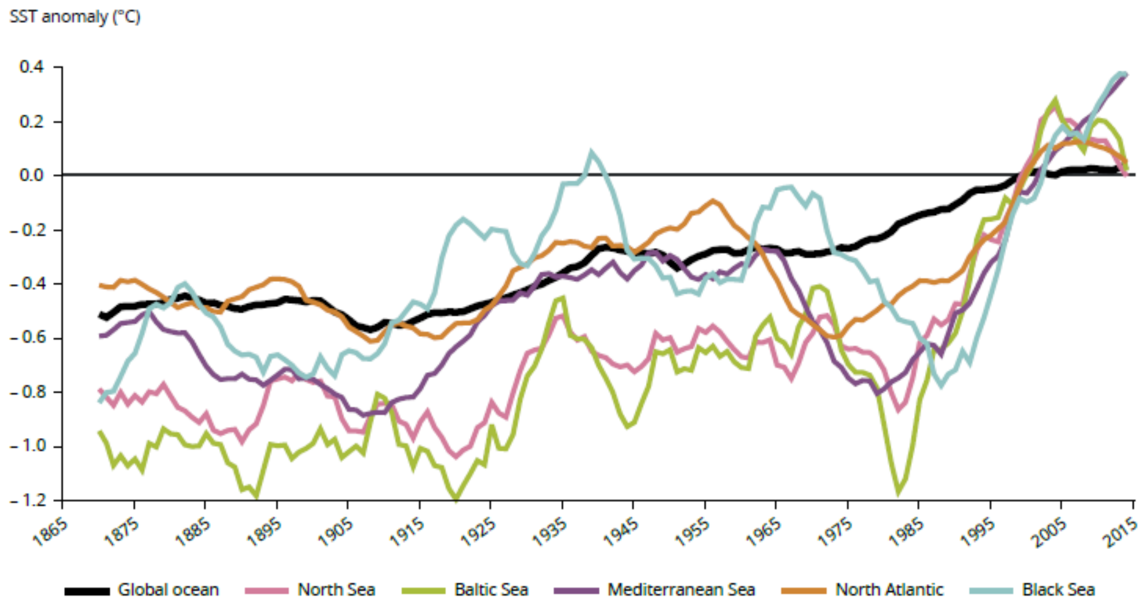
The impacts of these on marine biota have been observed to follow the predictions in shifts in distribution to higher latitudes and to deeper locations, advances in spring phenology, declines in calcification, and increases in the abundance of warm-water species (Poloczanska et al. 2016).

Increasing sea surface temperature

With the rise of atmospheric temperatures since the 1970s, European seas are warming up rapidly (Figure 3.45). Based on projections, it is expected that the SST will continue to increase (HELCOM, 2013a; Chust et al., 2014; IPCC, 2013; EEA, 2017c).

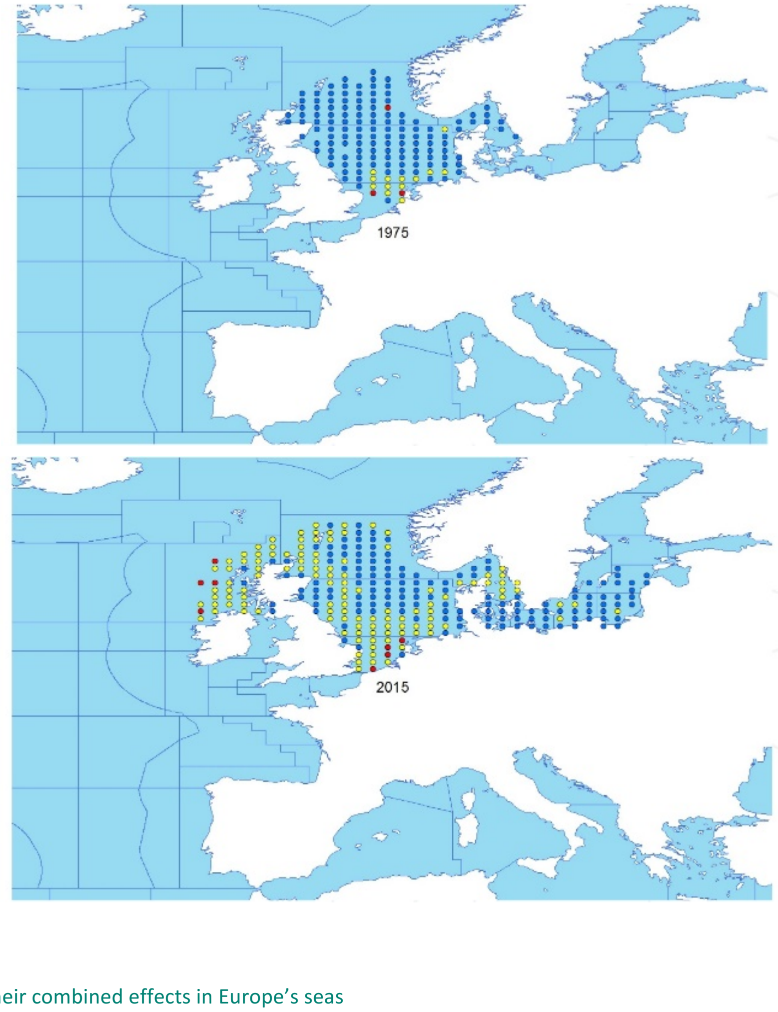
Rising sea temperatures influence stratification of the water column and thereby nutrient availability and oxygenation (Whitney et al., 2007; Stramma et al., 2010). In the Baltic Sea, extensive hypoxic and anoxic areas are already present and due to climate change driven modifications in stratification, it is expected that these areas will expand in the future.

Figure 3.45: Average sea surface temperature (°C), smoothed over 11 years, and expressed as anomalies with reference to the average temperature in the period 1993–2012. Source: EEA, 2017c.



Increased SST can also accelerate and cause more frequent algal blooms, which decrease the stability of marine ecosystems, and increase the risks for human health (Glibert et al., 2014). Higher SST causes a northwards movement of marine plankton and fish species observed in the Northeast Atlantic (Figure 3.46; Brander, 2007; Beaugrand, 2009; MCCIP, 2013).

Figure 3.46: Shifts in the proportion of Lusitanian (yellow and red) and Boreal species (blue), in the period 1995–2010, throughout the North Sea and the Baltic Sea. Source: EEA, 2019h



There is increasing evidence of a northward shift in the distribution of marine plant and animal species in previous decades (Poloczanska et al., 2016). This northward movement has been mainly assigned to global warming but also natural variability and human activities can influence species distributions and the combination of these are still poorly understood (Hoegh-Guldberg and Bruno, 2010). Several studies indicate that fish species have spread northward (Petitgas et al. 2012 and Petitgas et al., 2013) and this is related to an increased temperature in previous decades. Over the last 45 years, an increase in the number of fish species was observed in the Celtic Sea, the Greater North Sea and the Baltic Sea; observed changes are significant in the North Sea and in the Skagerrak-Kattegat, where significant correlations were also found between the L/B ratio and increased temperature, indicating that changes in fish distribution are related to climate change (Figure 3.46; EEA, 2019h). In the same period, there were no observed changes in the distribution of widely distributed fish species, which are less sensitive to temperature changes but are exposed to the same combination of increased sea temperature pressures related to human activities in the assessment areas (EEA, 2019h). Shifts in species distribution can have direct socio-economic effects in case of commercially important species due to changed food supply (Doney et al., 2012; MCCIP, 2013). Also, effects on spawning behaviour of pelagic fish species are expected (ICES, 2016). In the warmer waters of the eastern Mediterranean Sea, the annual mean rate of NIS spread from the Red Sea has increased to 150 % after 1998 (Raitsos et al., 2010; Chapter 3.1).

Melting of sea ice

A prominent effect of global warming is seen in long-term data in the melting of sea ice, i.e. its reduced temporal and spatial extent and thickness (von Schuckmanna et al., 2016; EEA, 2017c). Over the period 1979–2015, on average, 42,000 km^2 of sea ice in the Arctic region disappear per year in winter and 89,000 km^2 per year in summer (EEA, 2017c). The future projections, in general, show that the northern hemisphere ice-sheet will continue to disappear (Hezel et al., 2014; EEA, 2017c).

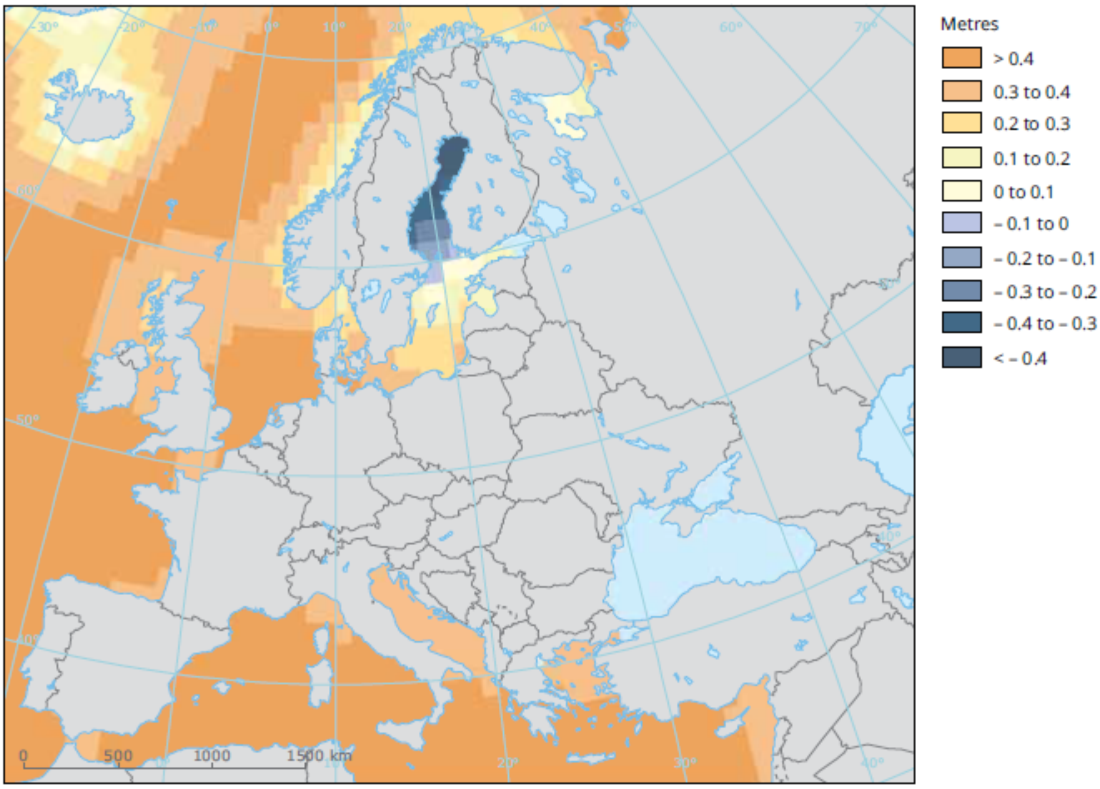
Sea ice occurs in polar and the Baltic Sea regions but affects climate also at lower latitudes (Gao et al., 2014). Large ice areas have a higher albedo than open sea and impact on water mass circulation, which is a driving force for the transport of heat from lower to higher latitudes (Smeed et al., 2013). Ice-sheets form specific marine ecosystems with specialized species (Laidre et al., 2008). Last but not least, the melting of ice contributes to sea level rise and this contribution will even increase in the future (EEA, 2017c).

Sea level rise

Climate change manifests, perhaps, the most strongly on SLR (von Schuckmann et al., 2016). SLR correlates with the ocean warming caused thermal expansion of water, and with sea ice melting. The global trend, detected between 1993 and 2015, showed SLR accounting for 3.3 ± 0.5 mm yr^{-1} and a rise of about 200 mm has taken place since the 1880s (Ablain et al., 2015; von Schuckmann et al., 2016; EEA, 2017b). It is noteworthy that sea level does not rise in a globally uniform manner due to the effects of wind, pressure, currents, evaporation and precipitation (Grinsted et al., 2015; Durack, 2015). The European regional SLR trends during 1993–2015 are generally considerably steeper than those observed at the global scale: at regional scale SLR is ranging between −5 and +5 mm yr^{-1}, while on a global scale around 3 mm yr^{-1} (von Schuckmann et al., 2016). Projections predict that the global mean sea level in the 21st Century will rise by 26–81 cm, depending on the emissions scenarios, and assuming that the Antarctic ice sheet remains stable (IPCC, 2014). The increased SLR will be most prominent in the Mediterranean and NE Atlantic (Figure 3.47).

Changes in extreme coastal high-water levels and SLR induced by climate change pose a significant threat to coastal ecosystems, communities and infrastructure with biophysical and socio-economic consequences (Neumann et al., 2015). By the end of the 21st Century, 5 million Europeans are currently under threat of 100-year extreme sea levels and could be annually at risk from coastal flooding under high-end warmings (Vousdoukas et al., 2017).

Figure 3.47: Projected change in relative sea level in the period 2081–2100 compared with 1986–2005 for the medium-to-low emissions scenario



Source: EEA, 2017a, c

Increasing ocean acidification

Oceans represent an important buffer zone for surplus anthropogenic CO_2 emitted into the atmosphere (Sabine et al., 2004). Increased ocean uptake of CO_2 results in a lowered pH. Since the 1980s, the ocean pH has decreased from 8.2 to less than 8.1, resulting in about a 30 % increased OA (EEA, 2017c). Average surface water pH is projected to decline further to between 8.05 and 7.75 by 2100, depending on future CO_2 emissions (EEA, 2017c).

OA affects species with calcium carbonate skeletons such as planktonic organisms (Riebesell et al., 2000) and reef-building corals causing shifts from coral to macroalgae dominance on reefs (Langdon et al., 2000; Orr et al., 2005; Enochs et al., 2015); rates of calcification in marine organisms have decreased by 11–44 % since pre-industrial times (Andersson et al., 2005). The effects of OA can also include increased mortality and decreased fertilisation rates, calcification rates and growth rates (Fabry et al., 2008; Hall-Spencer et al., 2008). Thus, through variable biotic responses, OA affects whole biological systems.

Changes in salinity

Higher temperatures cause increased water evaporation. Dry regions dominated by strong evaporation become saltier, while regions with strong precipitation experience salinity decreases (von Schuckmann et al., 2016). In the Mediterranean, SST anomalies and a projected decrease of a freshwater run–off to the basin could lead to increased salinity in the entire water column (EEA, 2017c; Adloff et al., 2015). In the Baltic Sea the decrease of salinity related to decreasing of sea ice extent is predicted (EEA, 2017c).

Due to the complexity and cascade effects of changes caused by rising CO_2 emissions it is impossible to fully predict all their biological and socio-economic effects. Climate change occurs rapidly and based on the projections will not subside. Even if the anthropogenic emissions of GHG will stop completely, the anthropogenic induced climate change will continue for many decades, due to high concentrations and the long residence time of GHG in the atmosphere (EEA, 2017c).

In general, our knowledge about marine ecosystem responses to multifactorial physicochemical alterations induced by climate changes is still poor. Under the influence of climate change, the marine ecosystems become more vulnerable to other anthropogenic pressures and their resilience is further decreasing (von Schuckmann et al., 2016).

Oceanic oxygen content decline

Decline in global oceanic oxygen content has been documented during the past five decades and the oxygen minimum zones are expanding (Schmidtko et al., 2017; IPPC, 2019). Ocean warming and acidification, loss of oxygen and changes in nutrient supplies, are already affecting the distribution and abundance of marine life in coastal areas, in the open ocean and at the seafloor. Warming-induced changes affect also spatial distribution and abundance of fish stocks, which brings new challenges to the management of fisheries (IPPC, 2019). These changes are also documented in EU seas (Figure 3.46).

4 Synthesis of activities, pressures and their combines effects in Europe's seas

KEY MESSAGES:

- Land and sea-based activities are causing a range of wide-spread pressures across Europe's seas. Especially, coastal waters and continental shelves, which are impacted by multiple pressures compared to further offshore areas.
- Based upon the spatial assessment, the most wide-spread pressures are related to climate change. Changes in ocean warming, ocean acidification and oxygen content decline indicate significant systemic changes in Europe's seas, which erode marine ecosystem resilience.
- Negative trends are beginning to reverse in areas where management measures have been implemented consistently to well-known pressures, e.g. in nutrients and some contaminants. 55.2 % of the assessed, commercially exploited fish and shellfish stocks across Europe's seas meet at least one out of two primary criteria defining the MSFD's 'good environmental status' objective for commercial fish and shellfish species.
- Many trends in pressures have not changed yet. For example, the numbers of non-indigenous species are still increasing, even though the speed of new introductions is slowing down. Widespread physical disturbance to the seafloor continues in coastal waters due to, especially, bottom trawling.
- Pressures from human activities on marine habitats and species are found in 93 % of Europe's marine area. The highest potential of combined effects from multiple pressures are found along coastal areas of the North Sea, Southern Baltic Sea, Adriatitc and Western Mediterranean. The most extensive combined effects in the shelf areas occur in the North Sea, in parts of the Baltic Sea and in the Adriatic Sea.

The marine environment is under heavy pressures from multiple human activities, but some signs of reduced pressures are already visible in Europe's seas (Chapter 3, Halpern et al., 2015). There are, however, several activities which are expanding to wider and deeper sea areas and the increasing coastal development is pressurizing the rich and diverse shallow water environment.

The current distribution and intensity of human activities in our seas is not within sustainable limits as clearly seen in the state of the marine environment (EEA, 2019a, b; Vaughan et al., 2019). This poses a challenge for the European Blue Growth objectives.

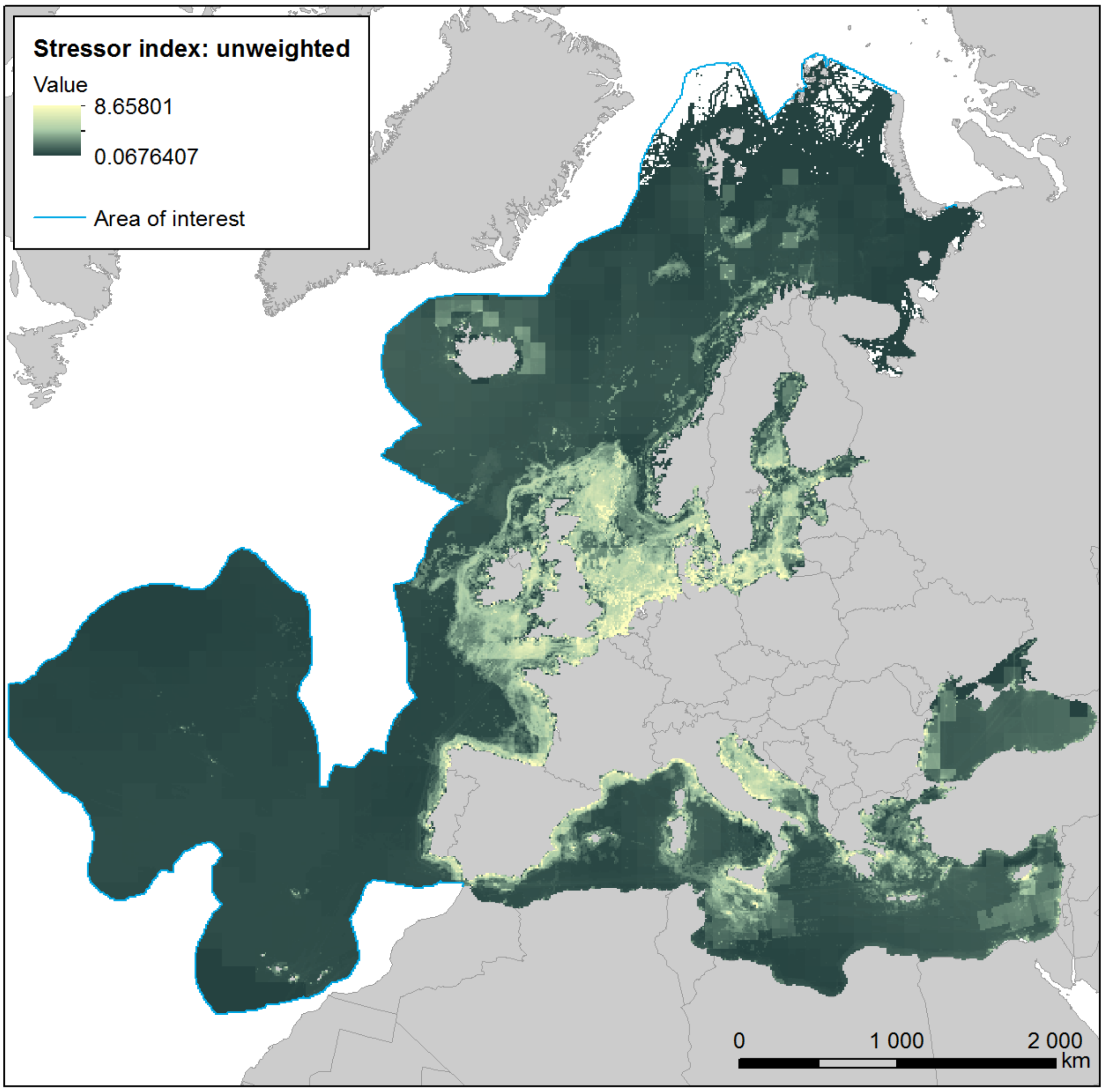
4.1 Europe's assessment of marine pressures

There is hardly any area in Europe's seas that is not affected by at least two anthropogenic pressures. Geographically, the widest pressures in our seas are climate-change driven changes, such as increased water temperature and acidification, and underwater noise. There is no doubt of the wide coverage of these pressures, but our current knowledge is too scarce to conclude on the magnitude of their effects on marine ecosystems. In the case of marine litter, our understanding of the extent of the problem is only evolving. It is clear that the species sensitivities differ to all these pressures and some species will respond earlier than others. For instance, dolphins seem to be more sensitive to impulsive noise than seals. Unfortunately, these pressures seem to be set to further increase in the future (Chapters 3.8 and 3.11).

Pressures, related to contaminants and eutrophication are still high in many of the marine areas, despite some improvements in the last decade. Numbers of NIS are increasing across Europe's seas, although in previous years there has been a decrease in the speed of new NIS introductions; some of these species are invasive. Pressures from spatially restricted activities such as fishing, and seabed exploitation are widely spread but show differences among the four marine regions.

Europe's coastal waters are under more diverse human impact than those offshore (Figure 4.1). Typically, these pressures extend to some kilometres offshore at most, but calculating the share of coastal waters under pressures such as hydrological changes, microbial pathogens or human disturbance (Chapters 3.5, 3.9, 3.10), these pressures become particularly evident. For instance, urbanization (causing human disturbance to wildlife) affects 31 % of all of Europe's coastal strip, coastal development causing hydromorphological changes covers 9 % and there is a risk for microbial pathogens in 5 % of the coastal strip

Figure 4.1: Index of human activities and land-based pollution pressures (nutrients and contaminants). The map shows a sum of all the intensity values of the spatial layers per 10 km × 10 km units. The data layers are described and available in Appendix A and the index method is described in Appendix C.



Severity of pressures in the four sea regions

The NE Atlantic has the widest area covered by fishing in Europe. Especially the demersal fisheries, which cover 33 % of the region's shelf area excl. Macaronesia (Figure 3.23; Table 3.3). The OSPAR assessment of the seabed showed that even 86 % of the seabed in the Greater North Sea and the Celtic Seas are disturbed by bottom-touching gear (OSPAR, 2017). For instance, 80–90 % of the muddy, sandy, coarse and mixed subtidal seabeds in the Southern Celtic Sea are under constant high disturbance. In the entire OSPAR area, 20 % of seagrass meadows, 40 % of the seamount area and 50 % of the sea-pen and burrowing megafauna habitat are under high disturbance from fishing. These habitats are listed as threatened and/or declining in the region (OSPAR, 2017). Nutrient inputs and eutrophication are spatially much more limited than fishing-related pressures; they disturb mainly in the southern North Sea, Skagerrak, English Channel and some coastal areas of the UK and Ireland. Almost 80 % of the marine area is under pressure due to pollution by contaminants, mainly metals, organobromines and PCBs (EEA, 2018b).

The Baltic Sea is known for its eutrophied state which has been identified as the most serious threat to the entire region (HELCOM 2018a). Circa 70,000 km^2 of the region's seafloor (17 %; http://maps.helcom.fi) is hypoxic and this area expands and shrinks annually. Although considerable cuts in nutrient inputs have been achieved, the historical loads have accumulated to seabed depressions and leak phosphorus under hypoxic conditions. Under the Baltic Sea Action Plan, countries have agreed on nutrient reduction targets. Also, hazardous substances exert high pressure on the Baltic ecosystem where the mixing of the shallow waters and slow water renewal times retain the substances in the system and the surrounding catchment areas pump new substances into the sea. Concentrations of several of the substances have declined for some decades, but the persistent substances, such as PCBs and brominated flame retardants, are still found in elevated levels from all over the region (HELCOM, 2018a). Fishing is often listed as the third environmental threat in the Baltic (HELCOM, 2018a). According to the HELCOM map service, bottom trawling covers ca. 48–56 % of the region, mainly concentrating in the southern sea area.

The Mediterranean Sea has the greatest number of NIS in Europe. In terms of species richness, the region receives five times more NIS than the other regions. As the region is also rich and diverse in marine life, the prevention of further invasions is a critical management challenge. Exploitation of fish stocks is another severe pressure on the Mediterranean native biota. Statistics have shown that ~ 78 % of stocks are overfished (FAO, 2018b), bycatch rates of other biota are very high and many of the bycaught elasmobranchs, seabirds and turtles have been included to the recent red lists (e.g. BirdLife International, 2015; Nieto et al., 2015; www.iucnredlist.org). Increasing tourism and coastal urbanization are also among the top pressures in the Mediterranean region even though this pressure is spatially limited to coastal zones. According to our analysis, about 38 % of the coastal strip in the region is affected by coastal development. Even if this may be an overestimation due to the coarse 10 km × 10 km resolution in the analysis, the effect together with other human disturbance is wider than the structures themselves.

The Black Sea EU waters are rather a small area compared to the entire region and this assessment does not adequately cover the non-EU waters due to data gaps. Nonetheless, it is clear that nutrient input is the main pressure, even though fishing also exerts a strong pressure on the ecosystem (FAO, 2018b). Effects of fishing are also visible in the state of the fish stocks; none of them are in a good state (Figure 3.23). A peculiar feature of the Black Sea is the permanent stratification under > 100 m and the anoxia underneath. From an ecosystem point of view, more worrying is, however, the shallow-water hypoxia that spreads widely in the NW areas and has degraded large areas of characteristic red algae zones (Borysova et al., 2005).

Fisheries exert multiple pressures on the seas

It is often the case that a single human activity exerts several pressures on the marine environment. While this can be said, for instance, of construction or aggregate extraction, the geographically most extensive activity in Europe's seas having multiple pressures is fishing. In addition to exploiting fish stocks, it damages the seabed, produces underwater noise and causes incidental bycatch of non-target fish, benthic biota, seabirds, turtles and marine mammals.

Demersal fishing by towed gear is by far the most impacting activity disturbing the benthic habitats (e.g. OSPAR, 2017); near 35 % in our spatial analysis of the Europe's shelf seabed area. This is an underestimation as the analysis included only the bigger fishing vessels. Spatially more accurate data from the northern regions has shown that up to 86 % of the assessed seabed in the Greater North Sea and Celtic Seas are disturbed (OSPAR, 2017). Similarly, the southern Baltic Sea sub-basins had bottom trawling coverage from 48 to 56 % (http://maps.helcom.fi). In the Mediterranean Sea, 55 % of the shelf area is bottom-trawled (Figure 3.23). The pressure is also high in the Northern Adriatic (98 %), South of Sicily (95 %), Ligurian and North Tyrrhenian Sea (71 %) and Northern Spain (43 %) (See FAO, 2018b). Our data set did not include bottom-trawling in the Black Sea.

Fish stock exploitation does not cause adverse effects on population if the stocks are managed sustainably. According to this assessment, there are great differences in sustainability of fishing between marine regions and fish stocks. Too many fishery target species or bycatch species are found from the lists of threatened species (see Chapter 3.2 and Vaughan et al., 2019) and the depleted stocks have clear consequences on the marine food web. The EU CFP aims at ensuring thriving fish stocks, which enable an economically viable fishing sector. Long-term trends in fishing indicate a shift to more sustainable fishing but still a majority of fish stocks are fished above the MSY targets.

Pollution trends are reversing

Polluting flows from catchment areas, atmosphere and sea-based activities rapidly increased in the mid-20th Century. Lakes and rivers were the first to contaminate and eutrophicate, but sea-scale symptoms were then seen in the semi-enclosed areas such as the Baltic Sea where the top predators crashed. As a shallow and semi-enclosed sea basin, the Baltic seems to be a forerunner in showing pollution problems (Reusch et al., 2018). The pollution has since become known in many coastal areas of Europe such as the Adriatic Sea, Southern North Sea and NW Black Sea, in addition to several estuaries and bays (Figure 3.18).

Integrated state assessments of eutrophication and contamination in Europe's seas show that 41 % and 79 % of the assessed sites are disturbed by eutrophication and contamination, respectively (EEA, 2018d). This is likely an underestimation as proper indicators and threshold values were not available for all the Europe's area.

The good news is that the input trends have turned downwards in many sea areas. The OSPAR and HELCOM assessments reveal that both the nitrogen and phosphorus inputs have decreased from the high levels of the 1990s (OSPAR, 2017; HELCOM, 2018b). In the Mediterranean, the peak years were in the early 2000s, but clear decreases are visible in both nitrogen and phosphorus concentrations (Figure 3.18). In the Black Sea, the riverine inputs have also decreased but the total inputs seem to have increased due to increased sewage inputs directly to the sea (see Chapter 3.3).

In case of hazardous substances, the improvement in contamination state is slow, albeit clearly visible for all the POP-substances, the radioactive substances and often also for heavy metals (OSPAR, 2017; HELCOM, 2018a).

Recovery from pollution is a long-term process. Persistent substances have accumulated on the seabed and still cause contamination effects decades after their bans. Still, the bans are effective, as in the case of TBT, of which concentrations are visibly declining in all the sediments. Similarly, cuts in phosphorus inputs in the Baltic Sea have clearly improved the eutrophication state (HELCOM, 2018a; EEA, 2019a).

4.2 Combined effects from multiple pressures

The spatial assessment of combined effects of multiple pressures informs us of the risks of human activities on marine ecosystem health. The method for this assessment was selected upon a review and it follows the same methodology as already in use in many of the Europe's seas and other parts of the world's ocean (Halpern et al., 2008; Coll et al., 2012; Korpinen et al., 2012; Andersen & Stock, 2013; Micheli et al., 2013; de Vries et al., 2011; van der Wal and Tamis, 2014). The method uses two types of spatial input layers: pressures and ecosystem components (species and/or habitats) and links these with so-called sensitivity scores, which estimate the sensitivity of an ecosystem component to a pressure. The method can be used in any spatial or temporal scale depending on input data. Moreover, it was noted that with increasing numbers of input data layers in the assessment, the output becomes less dependent on the sensitivity scores which have been often accused of being a source of uncertainty in the method.
For this assessment, 54 experts from the four marine regions replied to a survey which asked about the regional sensitivity of 23 habitats and 7 species groups for 14 pressures. The pressures were the same in all the four regions, but habitats and species groups differed partly if a certain habitat (e.g. bathyal seafloor in the Baltic Sea) or species group (e.g. seals in the Black Sea) does not occur in a region. The pressure layers and ecosystem component layers are described in Appendix A. Appendix C describes the CEA assessment method in detail and gives the survey results.

To properly assess cumulative effects, the synergistic and antagonistic effects on an ecosystem should be considered. Since this was not possible to do at the Europe's seas level, at this point, we use the term combined effects.

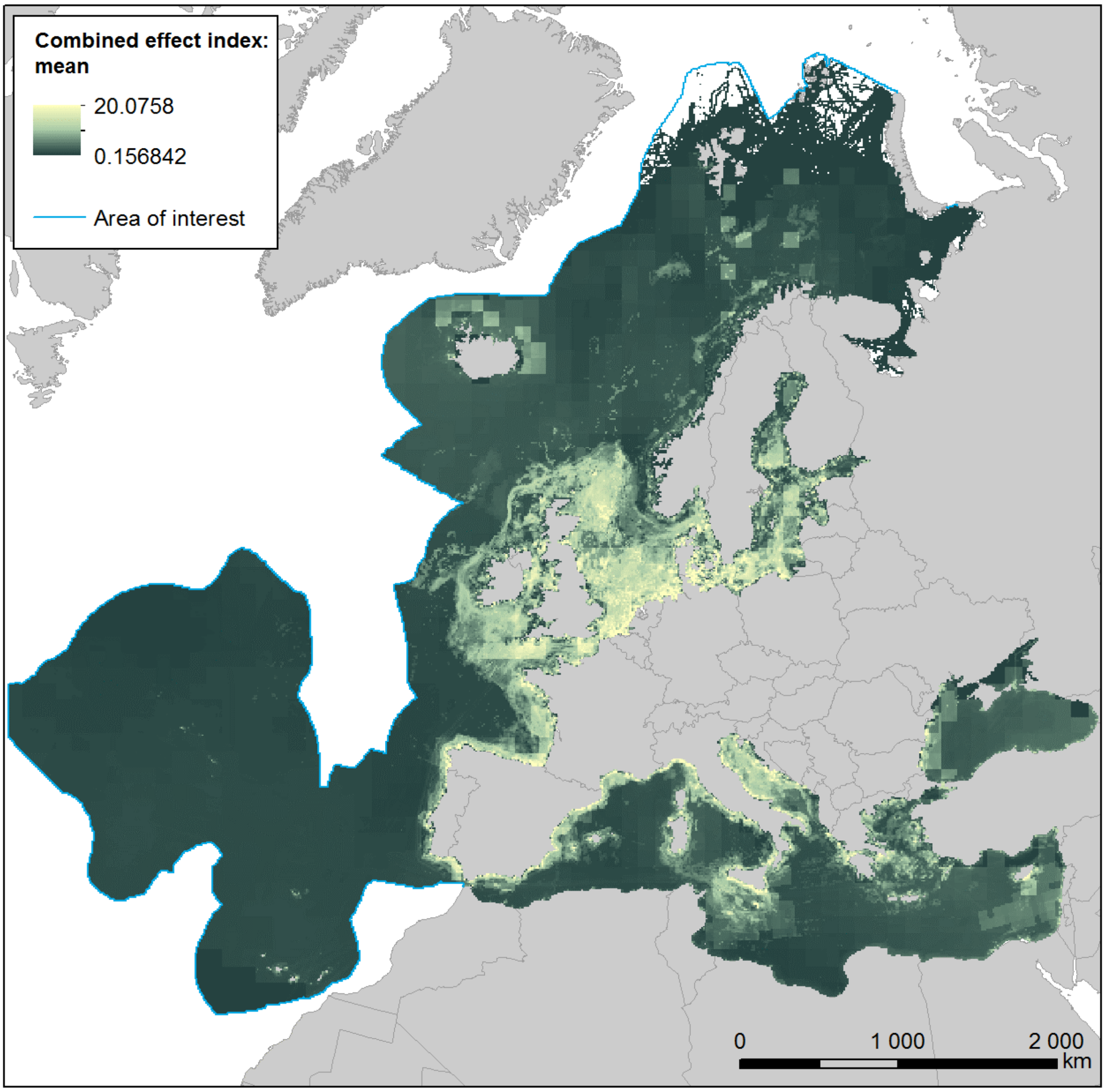
Combined effects in Europe's seas

Human activities cover the Europe's marine area widely (Figure 4.1). Potential effects from the activities on the seabed, water-column habitats and species are found in 93 % of the marine area (Figure 4.2). There are, however, strong gradients in the intensity of combined effects: coastal areas and the continental shelf are under much greater pressure than the offshore areas (Figure 4.3). If focusing on the areas which face the greatest combined effects – the higher half of the index scale – the distribution is clearly focused on the coastal areas of Central and Southern Europe (southern coast of the North Sea, English Channel, and Balearic Sea and in the Adriatic Sea). The most extensive combined effects in the shelf areas mostly occur in the North Sea and partly in the Baltic and Adriatic Sea. These areas are under several anthropogenic pressures, especially physical loss and disturbance due to intensive demersal fisheries, multiple coastal activities and pollution.

The lowest effects on the marine environment are found in the deep-sea areas outside the continental shelfs – the Northern and Southern parts of the Atlantic – and the Southern Mediterranean Sea. However, this can also be resulting from the gaps in the data, especially in any of the coastal seas like the Sea of Azov where some of the pressure datasets are lacking data.

At the scale of marine regions, the four marine regions are almost entirely affected by at least some anthropogenic effects. However, the intensity of the combined effects differs between the marine areas. In the Baltic Sea the combined effect per 10 x 10 km cell is 2–3 times greater than in the other regions. The sea basin is semi-enclosed, shallow and relatively small, and furthermore, it is surrounded by densely populated industrial countries. The NE Atlantic has the lowest combined effects due to its vast surface areas and depths. Even though the Mediterranean Sea and the Black Sea are also semi-enclosed from the ocean, they are deeper than the Baltic and especially the Mediterranean, which is a much larger area. The intensity of the combined effects in these areas is 40 % smaller than in the Baltic Sea (see however, Chapter 5 for data gaps).

Figure 4.2: Combined effects of human activities and pressures in Europe's seas. The index uses the sensitivity of habitats and species to anthropogenic pressures and calculates an additive effect of the pressures in 10 km × 10 km marine areas. The full method description is given in Appendix C. The confidence map of the data layers is given in Figure 6.1.



Combined effects from several human activities

The combined distribution of human activities and pressures in Europe's seas exerts potential effects that cumulate over the ecosystem (Figure 4.2). The results indicate that the coastal areas are under equally high potential effects across the entire Europe's coast. Offshore, the northern sea areas are generally under wider and more numerous activities and pressures than the southern areas. This is partly explained by the wider continental shelf and, hence, shallower waters. In the same way also the Adriatic Sea and mid-Mediterranean experience high pressures and combined effects (Figure 4.2). The overall difference between north and south may partly be an artefact caused by poor representation of the fishing effort in the southern regions. The fishing activities in the Mediterranean and the Black Sea are performed by smaller vessels not available for the data layers. The lack of data from non-European countries in these two regions is also visible in the result.

The pressures having potentially the greatest effects on the Europe's marine environment are hazardous substances, fish stock exploitation and bycatch from fishing, as well as noise. Due to the method, widely occurring pressures (e.g. pollution) are emphasized over local pressures (e.g. physical loss of habitats), even if the habitat sensitivity and pressure intensity are counted, too.

In the Baltic Sea, eutrophication and hazardous substances (incl. their effects) are the widest and most severe pressures (Figure 4.3; HELCOM, 2010, 2018a). Eutrophication and hazardous substances were standardized with the regionally agreed thresholds, ensuring realistic environmental pressure. Fishing and bycatch of mobile species cause potentially high effects in the region. The maritime traffic is the main source of noise and it is very intensive in the Baltic Sea and the ship sizes have continuously increased (HELCOM, 2018 b).

In the Black Sea, hazardous substances rank highest among the pressures, followed by underwater noise from maritime traffic and distribution of NIS (Figure 4.3). The latter result is also supported by the past assessments by the Black Sea Commission (2009) and discussed in Section 2.1. The extent of anoxia in the region was not adequately reflected in the analysis; the basin is permanently anoxic below 100–150 meters (see Section 3.3).

In the Mediterranean Sea, the highest pressure is bycatch of mobile species by bottom-touching gears (Figure 4.3). Almost similar effects are expected from continuous and impulsive underwater noise indicating shipping and intensive exploration for oil reserves (Maglio et al., 2016). The NIS are wide-spread and highly impacting in the region but currently mainly in the coastal waters, which is reflected as a lower position in this analysis.

In the NE Atlantic, hazardous substances rank as a top pressure but almost as high effects are expected from fishing and bycatch caused by it. Fishing is a widely and intensively practiced activity in the region's shelf area (Figure 4.3).

High combined effects on coastal waters

Photic coastal waters tend to host higher habitat diversity than offshore waters which also indicates higher combined effects on the coastal marine environment.

Figure 4.4 shows that the potential combined effects are clearly lower in the deeper waters beyond the continental shelf. This difference is, however, not visible in the small Baltic Sea where the entire area is continental shelf under several human uses and under historic pollution.

Figure 4.3: Combined effects of multiple pressures (relative scale) on the marine environment in the four EU MSFD regions. The scores are standardized to the surface area of each region. Due to the method, widely occurring pressures rank high in the figures. The layer of increased surface water temperature was omitted from the figures.

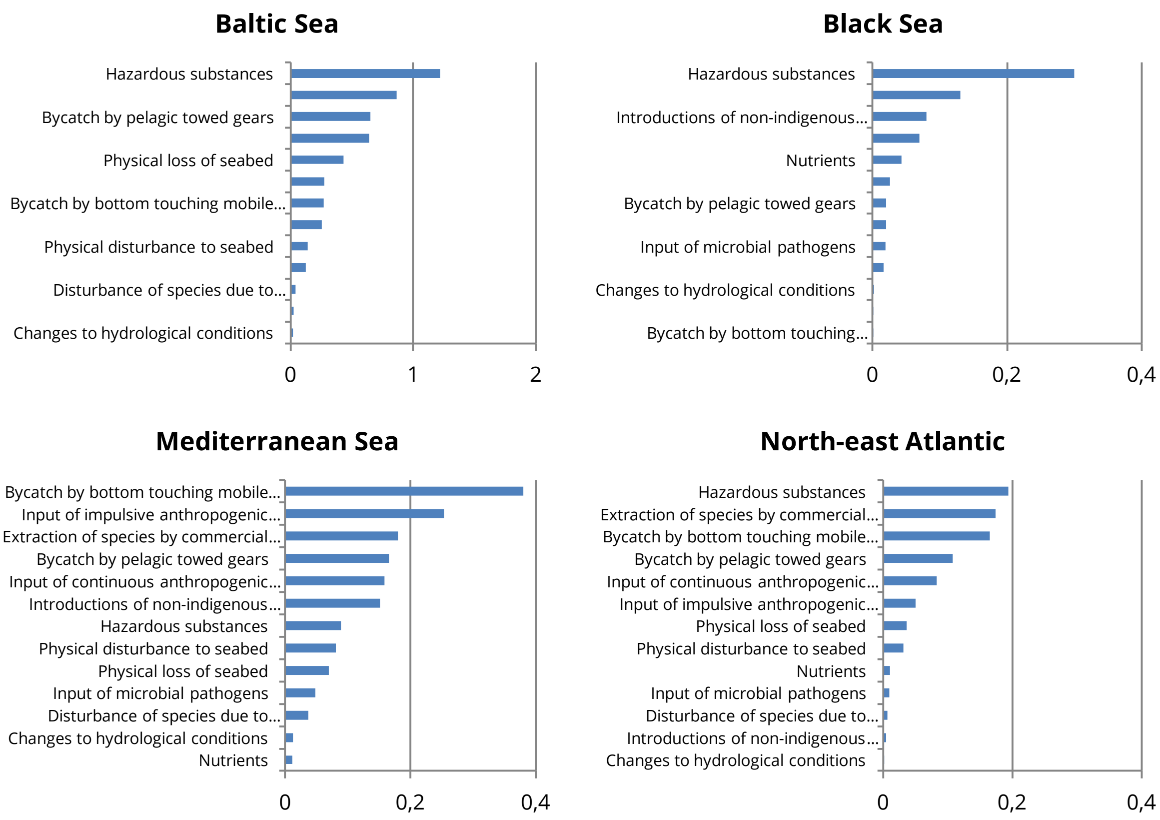
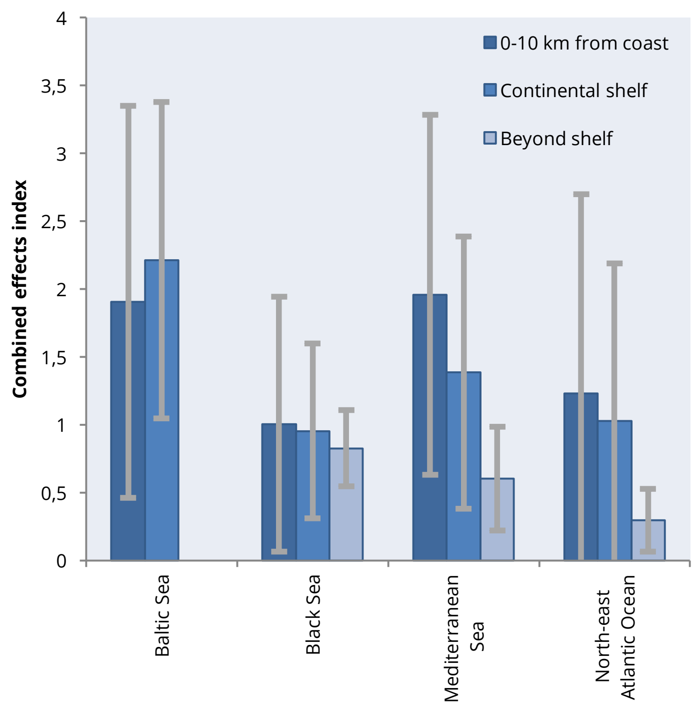


Figure 4.4: Comparison of combined effects caused by multiple pressures in coastal waters (0–10 km), shelf area and the offshore waters (beyond shelf). The score is calculated as the mean (and standard deviation) of all the 10 km × 10 km cells in the zone. The Baltic Sea is completely on the continental shelf.



Species and habitats under high pressures

The marine environment does not respond similarly to the pressures caused by human activities. According to the survey among European experts, shallower habitats, cold-water coral habitats, fish and turtles were considered, on average, more sensitive to human pressures than many other marine features (Appendix C).

Taking into account the different sensitivities and pressure distributions, the species and habitats were ranked by combined effects (Figure 4.5).

In the Baltic Sea, the three seal species are potentially the most affected ecosystem components, followed by the breeding birds and fish stocks.

In the Black Sea and the Mediterranean Sea, the most affected features are the toothed cetaceans and fish species. Also, the deeper sea-floor habitats and coralligenous algae rank high in the Mediterranean Sea.

In the NE Atlantic, the potentially top-most affected features are all the cetaceans, fish and seals.

Figure 4.6 shows potential combined effects on specific habitats: the known extent of seagrass meadows, saltmarshes, seamounts as well as formations of coralligenous algae and cold-water corals. Our results show that a relatively high amount of pressures affect almost the whole distribution area of these habitats. The depiction of adverse effects would, however, require state assessments which are not available.

Seagrass meadows are under the highest effects in the Baltic Sea, Black Sea and the Mediterranean Sea where all the habitat area has potential effects (Figure 4.6). Seagrass meadows are very sensitive to physical pressures, changes in the hydrological conditions and input of nutrients. Some of the seagrass in the NE Atlantic seem to face no effects.

Saltmarshes face potentially high effects in the Baltic Sea, Black Sea and the Mediterranean Sea (Figure 4.6). In the NE Atlantic, there seem to be areas of no combined effects on saltmarshes. The habitat is highly sensitive to physical pressures and changes in hydrological conditions.

Most seamounts in the Mediterranean Sea are potentially under high effects. This might be due to their sensitivity to demersal fishing activities. The seamounts in the NE Atlantic are potentially under lesser effects but only 3 % of their distribution is without any effects (Figure 4.6).

Cold water corals of the NE Atlantic Ocean and coralligenous formations of the Mediterranean and the Black Sea are disturbed in the majority of their distribution range. Only a few sites seem to be unaffected (Figure 4.6). The habitats are particularly sensitive to activities causing physical disturbance and loss, increased water temperatures and NIS.

4.3 Europe's pressures in the global context

According to a recent global assessment of combined effects of human activities, the world's ocean is heavily and widely impacted; hardly any area is left untouched (Halpern et al., 2015). The global assessment showed that especially the northern temperate (especially North Sea) and sub-tropical regions – but increasingly also tropical regions – are under heavy combined effects. Also, this assessment showed that practically the entire Europe's sea area is covered by anthropogenic effects. The three widest pressures in the Europe's seas are the same as in the global assessment (Figure 4.3).

Europe's seas stand out in the global assessment as highly impacted areas, but the global analysis indicates also a turning point towards a more sustainable level of activities. The commercial fishing activities decrease in 70–80 % of the ocean area (Halpern et al., 2015). In this assessment this was found especially in the northern marine regions where several fish stocks currently meet the MSY targets and spatial protection areas restrict, e.g., demersal destructive fisheries in large areas of seamounts. Similar turning points are seen in the nutrient inputs to the Baltic Sea (Reusch et al., 2018).

As the CEA method analyses the spatial width of pressures, it emphasizes the wide-spread pressures like noise and climate change. Although correct, this may shadow pressures which are more directly apparent at sites where humans operate. Focusing on those, overexploitation by fishing and habitat loss have been listed as the top pressures in several rankings of human pressures (e.g. Crain et al., 2009, HELCOM, 2018a). The habitat loss has been shown to be the reason for the global biodiversity crisis (Hoekstra et al., 2005) and also recognised as a major threat to the marine environment (Airoldi et al., 2008; Knapp et al., 2017).

Figure 4.5: Ranking of species and habitats under the greatest potential combined effects in the four EU MSFD regions. The pelagic habitats are not included in the figure.

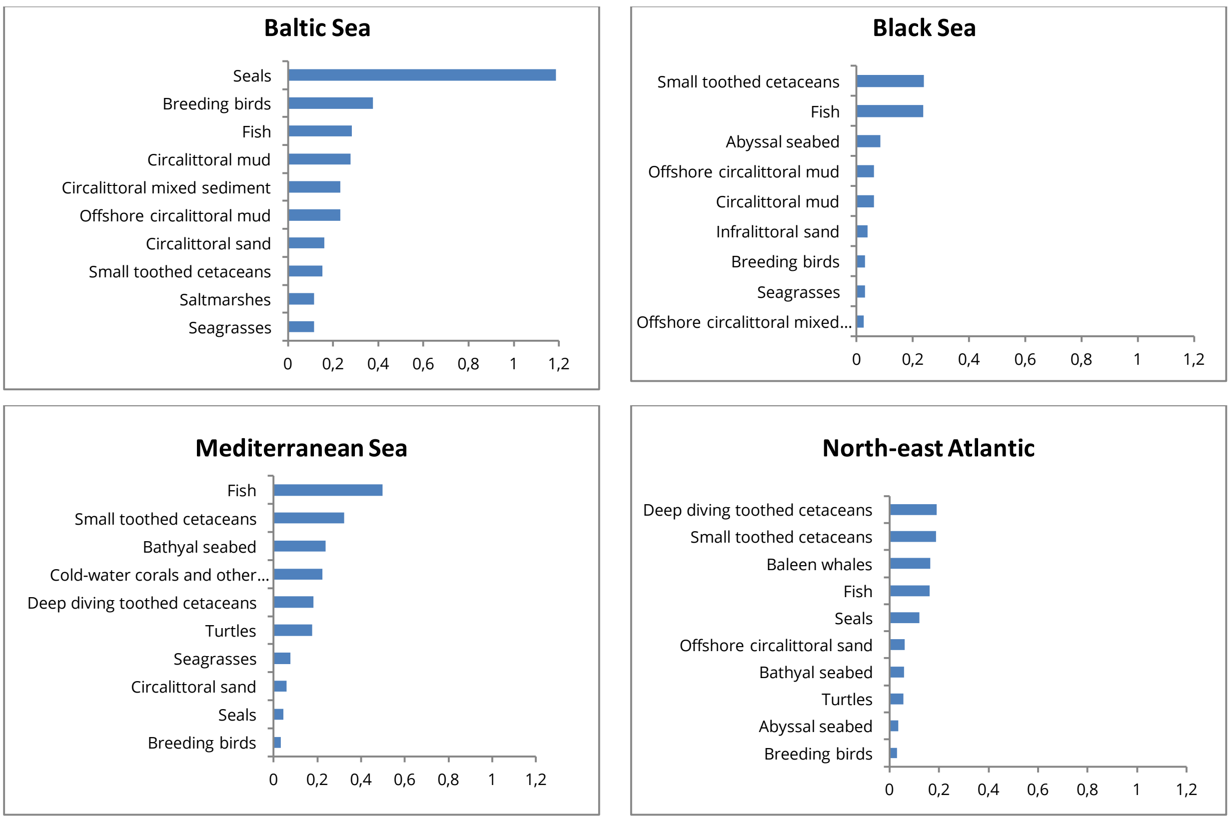
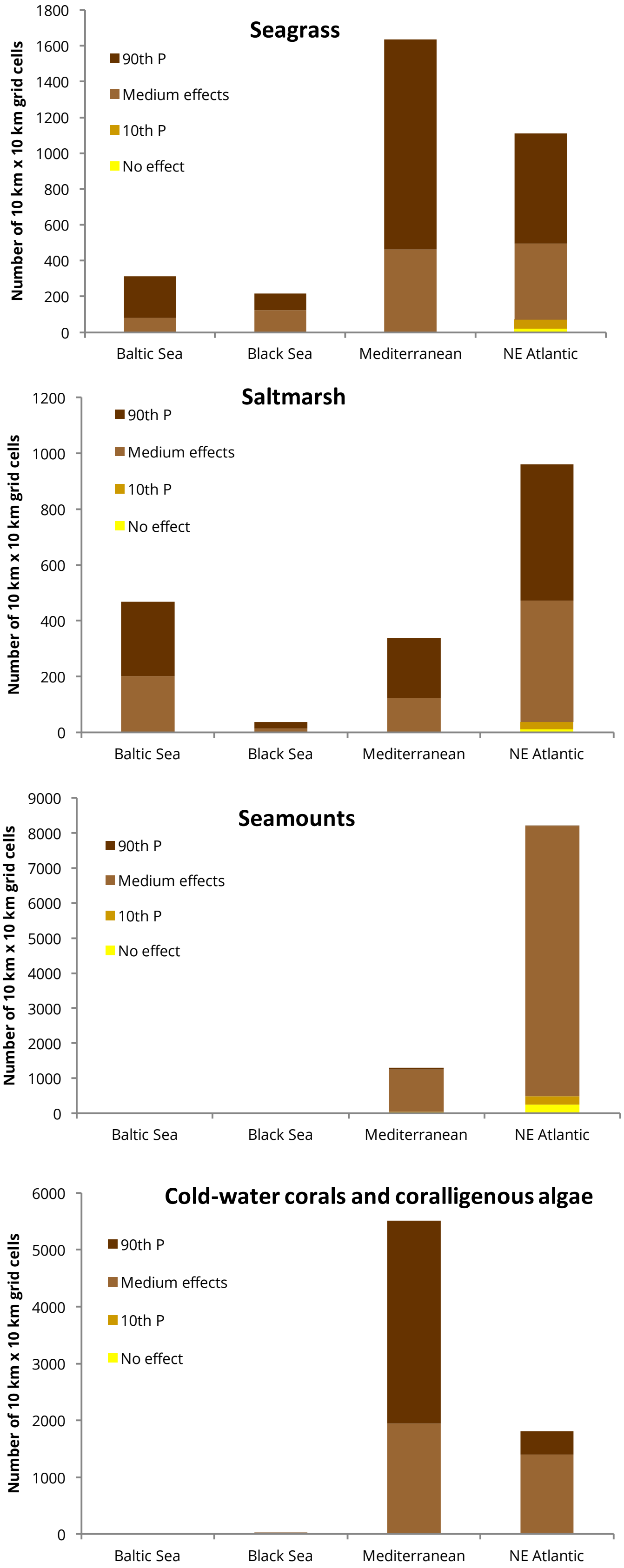


Figure 4.6: Extent of combined effects in seagrass meadows, saltmarshes, seamounts and cold-water coral and coralligenous algae is shown in their distribution area. Bars show the number of 10 km x 10 km grid cells under no effects, 10th and 90th percentile (P) of effects and effects between. See appendix A for the specific pressures present in the habitats.



4.4 Critical ecosystems under pressure

Geographically, the widest ecosystem effects in our seas can currently be seen in the state of fish stocks and the state of pelagic and benthic habitats, whereas the historic decline of marine mammals could also be included on the list. Pelagic habitats are directly affected by the warming of the sea surface, acidification and eutrophication. Benthic marine features are impacted by a wide range of targeted activities (e.g. fishing or extraction of minerals) and indirectly by bottom-touching fishing gear, abrasion by shipping in shallow-water areas and all the activities disturbing the seabed. About one fifth of the assessed habitats are currently threatened and an additional 11 % are near threatened (Gubbay et al., 2016). Many of the regionally identified habitats under decline are under constant pressure from bottom trawling (see Chapter 3.4).

Europe's marine fish are under heavy pressure. Specific assessment (Nieto et al., 2015) concluded that 7–25 % of all the Europe's marine fish species are threatened. The assessment showed that altogether 425 fish species are impacted by fishing activities, 58 of which are threatened (i.e., assessed as having an elevated risk of extinction). Over 40 % of the chondrichthyans i.e. sharks, rays, skates and chimaeras are threatened and for all of them the reason of threat is fishing or bycatch in fisheries. All the Europe's critically endangered fish species are chondrichthyans.

The greatest concentrations of threatened fish species appear off the Iberian Peninsula, the Mediterranean Sea and the Canary Islands (Nieto et al., 2015). In the Northeast Atlantic the waters around Iceland, the British Isles and Norway as well as the Azores also emerge as hotspots of threatened marine fishes.

5 Sustainable use of Europe's seas – towards clean, healthy and productive seas

KEY MESSAGES:

- The EU maritime economy is foreseen to further increase, leading to increased competition for marine natural capital (i.e. marine biotic and abiotic assets) by maritime sectors. In order to be sustainable, this increase needs to be decoupled from the degradation and depletion of marine ecosystem capital and take place within the current limits of marine ecosystems.
- In cases where cause-effect is direct and known, and where management was implemented, pressures on Europe's seas have decreased over time. Cumulative effects of human activities are currently still not considered for management or for planning of human activities at sea yet.
- Spatial protection measures – temporary closures, zoning and no entry areas – are a powerful element in the tool kit towards clean, healthy and productive seas.
- The future of our societies is at stake. It is time to join efforts and implement all our knowledge and use resources to achieve the sustainable use of Europe's seas. This will require profound changes in the way we use our seas, including delivering ecosystem-based management and an unprecedented level of socio-economic adaptation.

Many human activities at sea have been increasing over time and the intensity of the use of Europe's seas is foreseen to keep on increasing (Chapter 2). This is especially so in the view of technological developments making it feasible to build far away offshore or exploit resources in the deepest parts of the sea.

If the blue economy is to double in the next decade (EC, 2018a), the number of human activities at sea as well as their size and intensity are expected to further increase. As current challenges and competition for resources and space increase, so will pressures and their combined effects on the marine environment and its ecosystems. This will likely further degrade the, generally, current poor condition of marine ecosystems (Chapters 3 and 4). It will increase the degradation of ecosystem structures, processes and functions and further impair their capacity to supply ecosystem services (Chapter 2). In addition, increased demands and impacts on marine ecosystems will, ultimately, undermine their stability and resilience. We need to move away from such a negative scenario by halting and reversing the current degradation and depletion of marine ecosystem capital.

5.1 What is at stake from the degradation and depletion of marine ecosystem capital?[2]

Fulfilling our basic needs would be at stake. Many marine ecosystem services sustain people by providing us with vital direct inputs, such as seafood to eat and oxygen to breathe. However, these vital services are not doing well, for example the:

- Seafood and other nutritional outputs from wild animals' service across EU marine regions are affected by the current overexploitation of commercial fish and shellfish stocks (e.g. not fishing them at MSY) (Culhane et al., 2019). The decline in EU catches is coinciding with the decrease in abundance for almost all demersal stocks (Owen and Carpenter, 2018). This decline needed to be offset by stocks from elsewhere to meet demand (EEA, 2019j). The reliability of EU citizens solely on fish/shellfish caught in EU

[2] The content of this section contributed to and was finalised at the same time as the EEA 2019 'Marine Messages II' Report (EEA, 2019). For this reason, where topics overlap, the text used in both reports could be the same.

waters is measured by the EU 'Fish dependence day'. Despite signs of recovery for several stocks in the NE Atlantic and Baltic Sea (EEA, 2019j) and national self-sufficiency (e.g. Sweden, Estonia), this day has moved to earlier in the year by almost a month over 16 years – from 4 August in 2000 to 9 July in 2016 – at the latest available calculation. This means that the EU would consume its domestic fish and shellfish supply in just over half a year (Owen and Carpenter, 2018).

- The oxygen production service could potentially be affected by reductions in the abundance and diversity of phytoplankton (microalgae) linked to the climate crisis (Sekerci and Petrovskii, 2018) and eutrophication (EEA, 2019a). Given that marine ecosystems supply about 50 % of the oxygen in the air we breathe (Lalli and Parsons, 1993), which is mainly generated by phytoplankton (Behrenfeld et al., 2001), those reductions would lower its productivity, jeopardising the service (Boyce et al., 2010; Moore et al., 2018; Dutkiewicz et al., 2019).

Our well-being would be at stake. Many (other) marine ecosystem services relate to our wellbeing, i.e. to us being, e.g., comfortable, healthy, relaxed and happy. These are services such as:

- Global climate regulation, which, as noted, contributes to the habitability of our ambient environment (Culhane et al., 2019), and which would also be impacted by the above-mentioned reductions in phytoplankton productivity given that these organisms play a key role in carbon sequestration too (see review in Basu and Mackey, 2018).

- Waste nutrient removal and storage service type, which contributes to providing clean seawater for us to, e.g., swim in (Culhane et al., 2019). Phytoplankton, again, plays a key role in the supply of this service through nutrient sequestration (Sigman and Hain, 2012; Basu and Mackey, 2018), which means that the service could also be eventually impacted if phytoplankton levels keep on declining.

Our livelihoods and economy would be at stake. Revenue and jobs in those maritime sectors based on the ecological resource, and exploiting, mainly, provisioning, but also a few cultural marine ecosystem services, would be lost if the supply of these services reduces or stops. For example, there would be economic losses from reductions in the:

- The study from Carpenter and Esteban (2015) found that recovering stocks to their MSY would deliver 2 million tonnes of additional fish/shellfish per year, enough to meet the annual demand of 89 million EU citizens; € 1.6 billion additional gross revenues per year; and € 800 million additional net profits per year, which could support up to 20,000 new EU jobs. However, this study did not consider all EU marine regions nor non-quota species in the NE Atlantic region; meaning that the estimated costs of overfishing are likely to be much higher (Carpenter and Esteban, 2015).

- Recreation and leisure service, which can be used via tourist activities (Culhane et al., 2019), due to the effects of marine litter on tourism. Thus, marine litter impacts on marine biota/ecosystems cause the loss of € 350 million and 5,590 employees per year in this sector across the EU (EC, 2019e). Globally, the decline in marine ecosystem service delivery would bring an annual loss of $ 500–$ 2,500 billion in the value of benefits in case of 1–5 % of marine ecosystem services decline (Beaumont et al., 2019).

5.2 The future contribution of the blue economy to the sustainable use of Europe's seas?

The path towards sustainability for human activities at sea, requires, *inter alia*, that their management takes into consideration all the pressures these exert and their combined effects on our seas – as this has tended not to be the case so far. It also requires that maritime activities respect the current ecological limits of marine ecosystems in the context of the ecosystem-based approach and set and respect ecologically relevant boundaries. It follows that achieving sustainability for human activities at sea would, in general terms, require that:

1. Maritime sectors contribute to halt the degradation of marine ecosystems and help their recovery.
2. The maintenance and expansion of those sectors using marine ecosystem services needs to be commensurate with an understanding of the sustainability of the ecosystem capacity to supply them (Culhane et al., 2019).
3. Those sectors using marine abiotic resources and other abiotic marine outputs should not operate in a way that impairs marine ecosystem capacity for service supply either.

These premises could be met through moving from sectoral planning to the integrated planning and management of maritime activities as part of making ecosystem-based management operational. To note, however, that ecosystem-based management requires the integration of not only maritime activities but of all the human activities susceptible of impacting Europe's seas (EEA, 2019j). Doing so can, for the activities at sea part, be supported by maritime spatial planning. Using the ecosystem services approach can also help in this context by providing a shared perspective when having to resolve conflicting uses of Europe's seas, including accommodating the needs of the marine ecosystem itself (Granek et al. 2010; EEA 2015b; Celtic Seas Partnership 2016; Ivarsson et al. 2017; Veretennikov, 2019).

5.3 Challenges to be tackled

The EEA assessments of hazardous substances, eutrophication and state of biodiversity show that the Europe's marine waters are not in a good state (EEA, 2018d; EEA 2019a; ETC/ICM, 2019). Evidence from these assessments indicate that high levels of pressures and potential combined effects are found in several marine areas. The objective of this assessment is to indicate which pressures require Europe's attention as a priority.

Despite the positive development in the fishery sector, the southern fish stocks are clearly overfished, and the stocks are not in a good state. Also, more detailed assessments in the northern areas suggest that very high fishing intensity takes place in the Celtic Seas and parts of the North Sea which is seen in the state of demersal stocks and habitats (Fernandes and Cook, 2013; OSPAR, 2017). Rebuilding the overfished stocks would increase global fishery yields by 15 % and profits by 80 % (Sumaila et al., 2012; Costello et al., 2016).

The high fishing pressure and use of destructive gears cause high bycatch rates which endanger sensitive, declining and threatened species. A global study of > 4,700 fish stocks (75 % of annual catch) showed that fishing within the sustainable limits would reverse about half of the declining population trends of mammal, turtle and seabird populations which are assessed as threatened due to fishery bycatch (Burgess et al., 2018).

Currently, bycatch of sharks, rays and skates is high in the Mediterranean and NE Atlantic and seabird bycatch is especially high in the Celtic Seas and the southern Baltic (Žydelis et al., 2013; FAO, 2016). The Mediterranean has been shown to be a global hot spot for turtle, elasmobranch and marine mammal bycatch (Lewison et al., 2014; FAO, 2018b). To reduce the threat to the elasmobranchs, EU has set a strict 'fins attached' policy to all elasmobranch landings. In the Mediterranean, the Barcelona Convention has set capture and trade prohibitions for 10 species and plans for their recovery should be developed. In support of this, the General Fisheries Commission for the Mediterranean (GFCM) adopted a recommendation under which these shark species cannot be retained on board, transhipped, landed, transferred, stored, sold, displayed, or offered for sale. Additionally, in 2014, porbeagle was added to Appendix II of CITES, which regulates global trade, on top of many other shark species.

Spatial protection measures are suggested to be an effective tool in tackling the small-scale fisheries and bycatch pressures (FAO, 2016). This is currently a severe gap, as many marine protected areas (MPAs) do not restrict fishing in Europe's sea areas. About 64 % of Natura 2000 areas allow fishing and hunting (marine or freshwater) within the site and the most commonly cited human activity within protected areas was fishing (Tsiafouli et al., 2013). The EU Habitats Directive and Birds Directive require that conservation measures need to be set up for a Natura 2000 site for those pressures which threaten it. Also, the CFP offers different possibilities for such measures and some countries have recommended them jointly in the North Sea and the Baltic Sea (EC, 2018c).

Since 2006, the GFCM has established seven Fishery Restricted Areas (FRAs) in the Mediterranean Sea with the aim to ensure the protection of deep-sea sensitive habitats and of essential fish habitats. These areas are characterized by regulation and/or restriction of fishing activities, e.g. by total closures or prohibiting the use of some fishing gear. Elsewhere, seasonal permanent or real-time fisheries closures have been implemented in Iceland, Faroes, Norway, UK, France, and by the NEAFC to the high seas (Bailey et al., 2010).

The fishery closures have, however, been criticized for their complicated rules and high enforcement costs. A study showed that the simple no-entry MPAs are many times more effective in improving shark populations than conventional MPAs or even no-take MPAs (Frisch and Rizzari 2019). However, the use of MPAs has been also proposed as a way to mitigate the effects of climate change in the oceans (Roberts et al., 2017).

On the other hand, the nutrient inputs have been slowly declining for some years in all the sea regions (see Chapter 2.3), but the nutrient inputs are still very high in some locations and Europe's agriculture is still leaking too many tons of artificial fertilizers into rivers, estuaries and seas. The challenge with agriculture is the use of expensive fertilizers even though the soils nutrient balance would, in many fields, be sufficient for crop production. This could be enhanced by improving the soil structure. While animal manure could be a partial solution to the need of fertilization, there is also a structural challenge due to the spatial differentiation of animal husbandry (i.e. manure production) and crop fields where the manure could act as a fertilizer. Logistics to transport the manure are not in place. In the current situation, animal farms are overflowing with manure and overdosing nearby crop fields with it, also crop fields are using artificial fertilization.

5.4 Managing national and local pressures

Increasing coastal population, tourism and maritime activities have put our coastal waters under heavy pressures. These areas are in most cases managed by local or national authorities. In this assessment it was shown that the coastal ecosystems are particularly affected by coastal development, disturbance of wildlife by human presence and pollution by litter, pathogens and hazardous substances. It was also shown that coastal pressures have potentially very high combined effects on the marine ecosystem.

Many of the human activities degrading the marine environment require environmental impact assessments and permits to ensure that sensitive marine features are not adversely affected. Smaller activities such as household dredging can typically be carried out without permits and the number of these activities is high in densely populated coastal waters and therefore areas of different levels or zones of protection may be the only viable option to sustain good state in parts of our marine coastal waters. Linking those measures with the ecologically and Biologically Significant Areas (EBSA, https://www.cbd.int/ebsa/) may provide an optimal solution.

5.5 Expanding to the deep

The global need for raw materials increases and with technological advances, humanity is now looking for those they can find from the deep seafloor, at an increasing pace (Boetius and Hackel, 2018). Although the operations in the deep are currently mainly exploratory, the concern is that the very sensitive deep-sea bottoms will be disturbed on a wide scale. Evidence exists for the specialty of the manganese nodule habitats which provide the only hard substratum over much of the abyssal seafloor and thus host very different fauna than the adjacent areas.

In 1982 United Nations Convention on the Law of the Sea (UNCLOS) declared the seabed area beyond national jurisdiction and its mineral resources as the common heritage of mankind, to be administered for the benefit of mankind as a whole (see MIDAS, 2016). According to UNCLOS, all mineral exploration and exploitation activities are approved by the International Seabed Authority (ISA). The ISA has adopted regulations to prospect polymetallic nodules, polymetallic sulphides and cobalt-rich ferromanganese crusts as well as recommendations for the assessment of the possible environmental impacts arising from exploration for marine minerals. There has been recent scientific critique that the transparency of the ISA process could be improved (Ardron, 2016; Boetius and Haeckel, 2018). In 2015, the UN General Assembly set up a process to develop a legally binding instrument on conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (UN, 2015a). The process is still on-going (see Danovaro et al., 2017, for discussion).

The current ISA regulations are clear that if activities would have serious harmful effects on vulnerable marine ecosystems – hydrothermal vents, seamounts and cold-water corals – such effects must be prevented, or the activities not authorized to proceed. The activities must follow the precautionary effect of the Rio Declaration, best available technology and practices, technical and financial guarantees, requirements to provide recourse for compensation and the obligation to conduct an environmental impact assessment (MIDAS, 2016).

The sustainability and manageability of deep-sea mining is under a question mark, both economically and environmentally. Boetius and Haeckel (2018) estimated that an economically sustainable project would have to mine several hundred square kilometres, but that would not yet include the costs of environmental management.

5.6 Europe's pursuit for less impacted seas

In this assessment, it has been shown that Europe's seas are stressed by a multitude of pressures which operate on different geographical scales and this is seen as a degraded state of the environment (EEA 2019 b, c, d). It seems in the light of this assessment that time may not yet be ripe to fully launch the EU Blue Growth agenda into wider practice, as sustainable use is not within our grasp even with the current use of our waters.

Europe's actions to reduce anthropogenic pressures are heading in the right direction. The EU Member States have set up specific programmes of measures under the EU MSFD to reduce human impacts and achieve GES, by 2020. The European Commission has carried out an analysis of these programmes and concludes that:

Non-indigenous species. Ballast water management is the most common measure, used by 13 Member States, to reduce species introductions from shipping. Some measures by another 13 Member States were also set to prevent introductions from aquaculture.

The European Commission additionally recommended that Member States could add the IMO biofouling guidelines to the NIS prevention (EC, 2018e).

Commercial exploitation of fish and shellfish. 16 Member States have set measures to minimise pressures from fisheries and 14 Member States have set measures in place to recreational fisheries. The measures typically include reducing the size of the fishing fleet, reducing the total catch and banning fishing or some types of fishing practices (e.g. trawling) in certain areas. Many of the measures are targeted at overfished, fish stocks.

In light of this assessment and from EC recommendation (EC, 2018e), it seems that the impacts from small-scale and recreational fisheries require specific attention (see Chapter 3.2). Differences in national fishery management seem to have significant effects on fish stocks even within a sea area. Studies have reported how the western Adriatic Sea is more intensively fished resulting in low chondrichthyan abundance and diversity in contrast to the eastern Adriatic, where countries have stricter protection and management and hence have greater biomass and diversity of chondrichthyans (Soldo, 2012; Ferretti et al., 2013). The reason for this difference may be in the use of small-scale driftnet fisheries and the late adoption of the driftnet ban by Italy (Sala, 2016).

Another example is the state of the anadromous sea trout in the Baltic, where countries assess sea trout from 'least concern' to 'critically endangered'. Reasons for the different status classifications are local juvenile bycatch in coastal areas and riverine hydropower dams and degradation of spawning grounds (HELCOM, 2013b).

Nutrient inputs. All the EU Member States have taken measures in the river basins to reduce nutrient inputs. Many have also promoted sustainable aquaculture and agricultural practices, established Nitrogen Oxides (NOx) emission control areas for shipping, constructed port infrastructure for liquefied natural gas and controlled the discharge of untreated sewage from ships. The European Commission recommended that also nutrient inputs from the atmosphere and aquaculture should be addressed (EC, 2018e).

Hydrographical changes. The Member States Programmes of Measures do not include specific measures to address this pressure in the marine environment. As this pressure is typically dealt with through the environmental impact assessments, the European Commission recommended that hydrographical changes should be tackled rather at strategic level, than at project level and also include coastal development issues (EC, 2018e).

Inputs of contaminants. 10 Member States have enhanced regulating the discharge of contaminants, reduced the use of pesticides and improved aquaculture and dredging practices.

Atmospheric inputs of hazardous substances exert a major pressure source and therefore the European Commission recommended that this should be addressed in the Programme of Measures (EC, 2018e).

Marine litter. Very few Member States had direct measures to reduce litter, but the few exceptions included bans of single-use plastics. The majority of measures refer to the EU laws (waste management, urban wastewater treatment or port reception facilities). Waste management is going to be improved in the fisheries and aquaculture sectors.

A few years ago, marine litter was considered as a potential threat, but recent monitoring efforts have lifted it among the top pressures. Particularly in the Mediterranean Sea, litter is one of the major environmental challenges facing the ecosystem. Although RSCs have adopted regional litter action plans, the Member States actions to concretely tackle the litter issue seem to be weak. The European Strategy for Plastics in a Circular Economy (EC, 2018d) envisiged the EU being the leader in the transition process to the plastics of the future, building on a New Plastics Economy and circular economy goals (WEF, 2016). Despite the widespread impacts and considerable pressures that marine litter exerts in the underwater realms, it is evident that the marine litter problem has to be handled at source (EC, 2018e).

Underwater noise and other energy. The Member States measures include protecting sensitive areas from impulsive and continuous noise, developing less noisy ships and developing light systems on oil and gas platforms to reduce artificial light.

Underwater noise from shipping is a global pressure which is regulated through the IMO. IMO regulations can be applied to smaller areas and such have been done in Europe to reduce ships' nitrogen and sulphide emissions and sewage discharges in the Baltic Sea which is defined as a Particularly Sensitive Sea Area (PSSA) under the IMO. Other PSSAs in Europe are in Waddensee, Western Europe, the Canary Islands and the Bonifacio Strait in the Mediterranean (http://pssa.imo.org). Under such a definition, piloting and mandatory location reporting measures as well as avoidance areas and routeing measures can be applied to reduce vessels' impact on the ecosystem, e.g. collisions with cetaceans or underwater noise. IMO has already adopted non-compulsory guidelines to reduce underwater noise from commercial shipping (IMO, 2014), but no mandatory regulation is in place. The World Dredging Association has also submitted technical guidance on underwater sound in relation to dredging activities to the London Convention and Protocol Scientific Groups (WODA, 2013).

6 Knowledge

Expansion of European marine data during the past ten years has enabled thematically wider and spatially more accurate assessments which increase our knowledge of achieving the multiple environmental policy targets in Europe.

This assessment builds on European data and leans in many occasions on regional assessments in the four sea regions. Together with the other EEA's thematic assessments, they provide a holistic view of the drivers and pressures affecting the state of the marine environment.

Being the first European pressure assessment of the marine environment, we have identified gaps in our understanding of the relations between human activities, pressures and their effects and noted data gaps which have prevented evaluating key threats in our seas.

Assessment confidence was estimated in relation to the lack of data in the assessment (Figure 6.1). Most of the data were available for assessment of the Celtic Sea, North Sea and majority of the Baltic Sea. In other areas data gaps were significant, especially in the open seas.

Towards open environmental data

Environmental data has a long history of research interest which is still visible in:

i. reluctance in sharing even publicly financed data (national monitoring, EU and national projects),
ii. slow development of user-friendly data portals for data downloading,
iii. relatively few updated data products (e.g. indicators).

Sectoral barriers are another obstacle in data availability for environmental assessments. This is seen, e.g. in:

iv. reluctance in sharing data between administrative sectors, such as fishery, hunting or agricultural data,
v. ignorance of data availability from other sectors, such as marine related data products under the maritime sector or industrial emissions sector.

The European objective for increased maritime knowledge – visible e.g. in the EMODnet and Copernicus programmes – has provided good starting points for European wide assessments (Borja et al., 2019) and paved the way for more visible marine data and open data policies in Member States. Also, this assessment has utilized these EU data portals as well as Member State reporting under various directives.

Still, there are wide gaps in critical data to allow assessments of environmental sustainability of human activities at sea. This is particularly visible in sharing spatial fishery data (so-called VMS) which is currently available only from the NE Atlantic, the Baltic Sea and a few Member States elsewhere. Similarly, data on licenced or permitted activities (e.g. dumping and dredging) are only scarcely shared. This dual lack of data means underestimations of the benthic impacts in this assessment.

Similarly, assessments of eutrophication and contamination (this report and EEA, 2019a, b) suffered from data gaps in offshore measurements and open sharing of national indicator threshold values.

Improved regional cooperation

The requirement of the MSFD to coordinate assessments, monitoring and actions within marine regions has clearly improved regional cooperation. Coordinated indicator development and regional assessments took place at least in three marine regions. Also, a coordinated monitoring programme has been published for the Baltic Sea (http://www.helcom.fi/action-areas/monitoring-and-assessment).

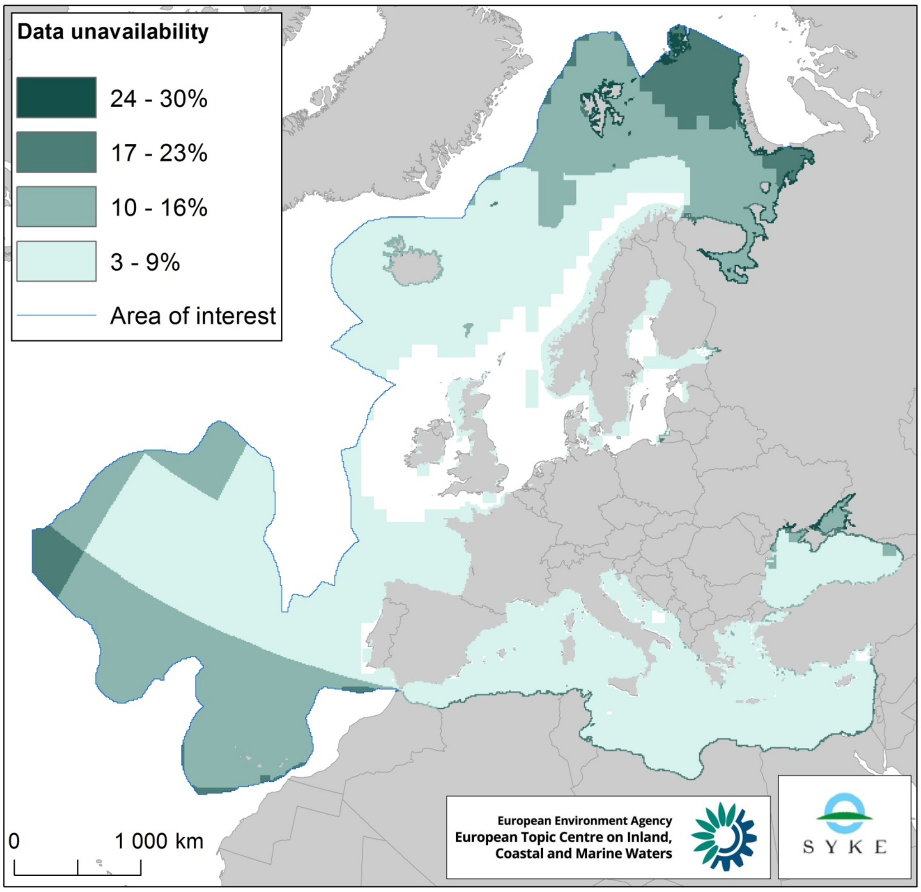
Inter-regional cooperation to develop and share have been carried out through research projects such as ODEMM and DEVOTES which have shown that targeted development work can root into practices and serve long after the project's life.

The EEA's role in sharing marine data

In 2018, the EEA launched the WISE-Marine portal (https://water.europa.eu/marine) with the objective of becoming the European main portal of marine data. The portal not only connects to Member States' reported data but also links with regional seas' data portals and other information sources.

In connection with the improvements in data availability (e.g. EMODnet, Copernicus) the EEA has begun developing marine data products such as indicators and spatial layers which have served the thematic assessments of the marine environment and will be maintained as stand-alone products for other uses, too.

Figure 6.1: Assessment confidence as estimated by the lack of data layers in this assessment. In white areas, all layers are available.



7 Supporting material

Appendix A: The Online Supporting Material of this assessment is available in the web-based version of this report at http://eea.europa.eu. It describes all of the spatial data layers of pressures and ecosystem components (habitats and species groups).

Appendix B: Summary of the spatial distributions of pressures. The summary presents the area and % coverage of the pressures in marine regions, the whole assessment area and in the three zones from coast to offshore.

Appendix C: Description of the assessment method used to run the cumulative/combined effects assessment and lists of ecosystem sensitivity scores for each of the 14 pressures used in the spatial assessment of combined effects.

Appendix D: Europe's seas contribution to the lives of EU citizens.

Appendix E: Cumulative Impact of Marine Alien Species (CIMPAL) in European Seas.

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Appendix A.

The Online Supporting Material of this assessment is available in the web-based version of this report at http://eea.europa.eu. It describes all of the spatial data layers of pressures and ecosystem components (habitats and species groups).

Appendix B. Summary of the spatial distributions of pressures

Spatial distributions of pressures were analysed for the European marine area and divided into four marine regions and three zones representing coastal strip (0–10 km from the coastline), continental shelf (from the outer border of the coastal strip to the 1 000 m depth isocline) and the offshore area beyond the shelf zone up to the border of the assessment area. The pressures were assessed in 10 km x 10 km grid cells, where occurrence of a pressure was assumed to cover the entire cell. This leads to overestimation of the pressure and hence the areal estimates should not be taken as an accurate presentation of the pressure distribution. Underestimation of pressure extent may also arise, but the reason for that are data gaps (described in Chapter 3 for each pressure).

Table B1 Invasive alien species: The invasive alien species distribution is based on the estimated geographical distribution of 85 species, which are known to be invasive

	Class	Regions								Total	
		Baltic Sea		Black Sea		Mediterranean Sea		NE Atlantic Ocean			
		km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Region	Total area *	466,100		520,100		2,674,900		11,335,100		14,996,200	
	No data	0	0	0	0	0	0	0	0	0	0
	No pressure	382,800	82	81,600	16	181,900	7	1,549,500	14	2,195,800	15
	Pressure	83,300	18	438,500	84	2,493,000	93	9,785,600	86	12,800,400	85
Coastal	Coastal area *	172,900		106,600		439,900		757,600		1,477,000	
	No data	0	0	0	0	0	0	0	0	0	0
	No pressure	116,300	67	0	0	7,900	2	566,000	75	690,200	47
	Pressure	56,600	33	106,600	100	432,000	98	191,600	25	786,800	53
Shelf	Shelf area *	293,200		143,100		773,500		3,584,200		4,794,000	
	No data	0	0	0	0	0	0	0	0	0	0
	No pressure	266,500	91	0	0	456,500	59	3,538,600	99	4,261,600	89
	Pressure	26,700	9	143,100	100	317,000	41	45,600	1	532,400	11
Offshore	Offshore area *	0		270,400		1,461,500		6,993,300		8,725,200	
	No data	-	-	0	0	0	0	0	0	0	0
	No pressure	-	-	0	0	1,351,900	93	6,992,800	> 99	8,344,700	96
	Pressure	-	-	270,400	100	109,600	7	500	< 1	380,500	4

*) Note that the area is calculated from the 10 km x 10 km grid cells and overestimates the real geographical area.

Table B2 Commercial fish catches by towed gear: The spatial layer was made by combining stock landings data from reported catch area and the spatial effort data (all gear combined) from the same area. The outcome represents an approximation of the areas of fishing and still gives information of the magnitude of fish catches between the fishing areas (i.e. the ICES rectangles in the NE Atlantic Ocean and the Baltic Sea and the FAO areas in the Mediterranean Sea and Black Sea)

	Class	Regions								Total	
		Baltic Sea		Black Sea		Mediterranean Sea		NE Atlantic Ocean			
		km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Region	Total area *	466,100		520,100		2,674,900		1,1335,100		14,996,200	
	No data	27,400	6 %	0	0 %	800	0 %	1,934,600	17 %	1,962,800	13 %
	No pressure	192,400	41 %	510,400	98 %	1,968,400	74 %	7,813,000	69 %	10,484,200	70 %
	Pressure	246,300	53 %	9,700	2 %	705,700	26 %	1,587,500	14 %	2,549,200	17 %
Coastal	Coastal area *	172,900		106,600		439, 900		757,600		1,477,000	
	No data	12,700	7 %	0	0 %	500	0 %	19,900	3 %	33,100	2 %
	No pressure	113,700	66 %	103,200	97 %	275,500	63 %	545,900	72 %	1,038,300	70 %
	Pressure	46,500	27 %	3,400	3 %	163,900	37 %	191,800	25 %	405,600	27 %
Shelf	Shelf area *	293,200		143,100		773,500		3,584,200		4,794,000	
	No data	14,700	5 %	0	0 %	300	0 %	21,700	1 %	36,700	1 %
	No pressure	78,700	27 %	136,800	96 %	398,000	51 %	2,360,300	66 %	2,973,800	62 %
	Pressure	199,800	68 %	6,300	4 %	375,200	49 %	1,202,200	34 %	1,783,500	37 %
Offshore	Offshore area *	0		270,400		1,461,500		6,993,300		8,725,200	
	No data	-	-	0	0 %	0	0 %	1,893,000	27 %	1,893,000	22 %
	No pressure	-	-	270,400	100 %	1,294,900	89 %	4,906,800	70 %	6,472,100	74 %
	Pressure	-	-	0	0 %	166,600	11 %	193,500	3 %	360,100	4 %

*) Note that the area is calculated from the 10 km x 10 km grid cells and overestimates the real geographical area.

Table B3 Bycatch fish catches by pelagic towed gear: The spatial layer was made by combining effort data from ICES (NE Atlantic and Baltic Sea) and effort data from AIS (Mediterranean and Black Sea).

	Class	Regions								Total	
		Baltic Sea		Black Sea		Mediterranean Sea		NE Atlantic Ocean			
		km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Region	Total area *	466,100		520,100		2,674,900		11,335,100		14,996,200	
	No data	27,400	6 %	0	0 %	0	0 %	0	0 %	27,400	0 %
	No pressure	208,300	45 %	509,800	98 %	2,293,500	86 %	10,470,100	92 %	1,341,700	90 %
	Pressure	230,400	49 %	10,300	2 %	381,400	14 %	865,000	8 %	1,487,100	10 %
Coastal	Coastal area *	172,900		106,600		439,900		757,600		1,477,000	
	No data	12,700	7 %	0	0 %	0	0 %	0	0 %	12,700	1 %
	No pressure	121,000	70 %	102,600	96 %	308,900	70 %	660,500	87 %	1,193,000	81 %
	Pressure	39,200	23 %	4,000	4 %	131,000	30 %	97,100	13 %	271,300	18 %
Shelf	Shelf area *	293,200		143,100		773,500		3,584,200		4,794,000	
	No data	14,700	5 %	0	0 %	0	0 %	0	0 %	14,700	0 %
	No pressure	87,300	30 %	136,800	96 %	612,600	79 %	2,962,900	83 %	3,799,600	79 %
	Pressure	191,200	65 %	6,300	4 %	160,900	21 %	621,300	17 %	979,700	20 %
Offshore	Offshore area *	0		270,400		1,461,500		6,993,300		8,725,200	
	No data	-	-	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	-	-	270,400	100 %	1,372,000	94 %	6,846,700	98 %	8,489,100	97 %
	Pressure	-	-	0	0 %	89,500	6 %	146,600	2 %	236,100	3 %

*) Note that the area is calculated from the 10 km x 10 km grid cells and overestimates the real geographical area.

Table B4 Bycatch fish catches by demersal towed gear: The spatial layer was made by combining effort data from ICES (NE Atlantic and Baltic Sea) and effort data from AIS (Mediterranean and Black Sea).

	Class	Regions								Total	
		Baltic Sea		Black Sea		Mediterranean Sea		NE Atlantic Ocean			
		km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Region	Total area *	466,100		520,100		2,674,900		11,335,100		14,996,200	
	No data	27,400	6 %	0	0 %	0	0 %	0	0 %	27,400	0 %
	No pressure	344,200	74 %	520,000	100 %	1,918,800	72 %	9,891,500	87 %	12,674,500	85 %
	Pressure	94,500	20 %	100	0 %	756,100	28 %	1,443,600	13 %	2,294,300	15 %
Coastal	Coastal area *	172,900		106,600		439,900		757,600		1,477,000	
	No data	12,700	7 %	0	0 %	0	0 %	0	0 %	12,700	1 %
	No pressure	141,700	82 %	106,500	100 %	242,600	55 %	584,200	77 %	1,075,000	73 %
	Pressure	18,500	11 %	100	0 %	197,300	45 %	173,400	23 %	389,300	26 %
Shelf	Shelf area *	293,200		143,100		773,500		3,584,200		4,794,000	
	No data	14,700	5 %	0	0 %	0	0 %	0	0 %	14,700	0 %
	No pressure	202,500	69 %	143,100	100 %	350,000	45 %	2,415,600	67 %	3,111,200	65 %
	Pressure	76,000	26 %	0	0 %	423,500	55 %	1,168,600	33 %	1,668,100	35 %
Offshore	Offshore area *	0		270,400		1,461,500		6,993,300		8,725,200	
	No data	-	-	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	-	-	270,400	100 %	1,326,200	91 %	6,891,700	99 %	8,488,300	97 %
	Pressure	-	-	0	0 %	135,300	9 %	101,600	1 %	236,900	3 %

*) Note that the area is calculated from the 10 km x 10 km grid cells and overestimates the real geographical area.

Table B5 Nutrient inputs: The layer is based on the integrated assessment of eutrophication status (EEA, 2019a). The coastal status is assessed for 10 km x 10 km grid cells, but 100 km x 100 km cells were used for the other areas. The indicator information was assumed to be representative for the entire cell area.

	Class	Regions								Total	
		Baltic Sea		Black Sea		Mediterranean Sea		NE Atlantic Ocean			
		km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Region	Total area *	466,100		520,100		2,674,900		11,335,100		14,996,200	
	No data	5,900	1 %	471,800	91 %	2,547,800	95 %	9,320,900	82 %	12,346,400	82 %
	No pressure	5,100	1 %	22,700	4 %	100,400	4 %	1,856,100	16 %	1,984,300	13 %
	Pressure	455,100	98 %	25,600	5 %	26,700	1 %	158,100	1 %	665,500	4 %
Coastal	Coastal area *	172,900		106,600		439,900		757,600		1,477,000	
	No data	5,900	3 %	94,500	89 %	347,500	79 %	418,000	55 %	865,900	59 %
	No pressure	5,100	3 %	5,400	5 %	77,200	18 %	275,200	36 %	362,900	25 %
	Pressure	161,900	94 %	6,700	6 %	15,200	3 %	64,400	9 %	248,200	17 %
Shelf	Shelf area *	293,200		143,100		773,500		3,584,200		4,794,000	
	No data	0	0 %	128,200	90 %	746,100	96 %	2,294,600	64 %	3,168,900	66 %
	No pressure	0	0 %	3,100	2 %	21,000	3 %	1,195,900	33 %	1,220,000	25 %
	Pressure	293,200	100 %	11,800	8 %	6,400	1 %	93,700	3 %	405,100	8 %
Offshore	Offshore area *	0		270,400		1,461,500		6,993,300		8,725,200	
	No data	-	-	0	0 %	1,454,200	100 %	6,608,300	94 %	8,062,500	92 %
	No pressure	-	-	263,300	97 %	2,200	0 %	385,000	6 %	650,500	7 %
	Pressure	-	-	7,100	3 %	5,100	0 %	0	0 %	12,200	0 %

*) Note that the area is calculated from the 10 km x 10 km grid cells and overestimates the real geographical area.

Table B6 Physical loss of seabed: The distribution of physical loss of seabed was calculated for the 10 km x 10 km grid cells and gives an overestimation of the point-like pressure. Accurate estimations should be calculated from the original spatial layers of human activities (see Appendix A).

	Class	Regions								Total	
		Baltic Sea		Black Sea		Mediterranean Sea		NE Atlantic Ocean			
		km²	%	km²	%	km²	%	km²	%	km²	%
Region	Total area *	466,100		520,100		2,674,900		11,335,100		14,996,200	
	No data	0	0 %	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	390,600	84 %	497,800	96 %	2,576,500	96 %	11,088,500	98 %	14,553,400	97 %
	Pressure	75,500	16 %	22,300	4 %	98,400	4 %	246,600	2 %	442,800	3 %
Coastal	Coastal area *	172,900		106,600		439,900		757,600		1,477,000	
	No data	0	0 %	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	109,200	63 %	86,600	81 %	350,900	80 %	593,700	78 %	1,140,400	77 %
	Pressure	63,700	37 %	20,000	19 %	89,000	20 %	163,900	22 %	336,600	23 %
Shelf	Shelf area *	293,200		143,100		773,500		3,584,200		4,794,000	
	No data	0	0 %	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	281,400	96 %	140,800	98 %	764,400	99 %	3,502,600	98 %	4,689,200	98 %
	Pressure	11,800	4 %	2,300	2 %	9,100	1 %	81,600	2 %	104,800	2 %
Offshore	Offshore area *	0		270,400		1,461,500		6,993,300		8,725,200	
	No data	-	-	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	-	-	270,400	100 %	1,461,200	100 %	6,992,200	100 %	8,723,800	100 %
	Pressure	-	-	0	0 %	300	0 %	1,100	0 %	1,400	0 %

*) Note that the area is calculated from the 10 km x 10 km grid cells and overestimates the real geographical area.

Table B7 Physical disturbance to seabed: The distribution of physical disturbance to seabed includes a range of human activities damaging seabed either by abrasion or siltation. No distinction has been made to classify the pressure to depict adverse effects. Physical disturbance to seabed was calculated for the 10 km x 10 km grid cells and gives an overestimation of the pressure.

	Class	Regions								Total	
		Baltic Sea		Black Sea		Mediterranean Sea		NE Atlantic Ocean			
		km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Region	Total area *	466,100		520,100		2,674,900		11,335,100		14,996,200	
	No data	0	0 %	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	98,500	21 %	382,400	74 %	1,699,200	64 %	9,339,100	82 %	11,519,200	77 %
	Pressure	367,600	79 %	137,700	26 %	975,700	36 %	1,996,000	18 %	3,477,000	23 %
Coastal	Coastal area *	172,900		106,600		439,900		757,600		1,477,000	
	No data	0	0 %	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	12,100	7 %	27,500	26 %	81,700	19 %	185,900	25 %	307,200	21 %
	Pressure	160,800	93 %	79,100	74 %	358,200	81 %	571,700	75 %	1,169,800	79 %
Shelf	Shelf area *	293,200		143,100		773,500		3,584,200		4,794,000	
	No data	0	0 %	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	86,400	29 %	84,500	59 %	292,000	38 %	2,264,600	63 %	2,727,500	57 %
	Pressure	206,800	71 %	58,600	41 %	481,500	62 %	1,319,600	37 %	2,066,500	43 %
Offshore	Offshore area *	0		270,400		1,461,500		6,993,300		8,725,200	
	No data	-	-	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	-	-	270,400	100 %	1,447,900	99 %	6,888,600	99 %	8,606,900	99 %
	Pressure	-	-	0	0 %	13,600	1 %	104,700	1 %	118,300	1 %

*) Note that the area is calculated from the 10 km x 10 km grid cells and overestimates the real geographical area.

Table B8 Changes to hydrographical conditions: The pressure is calculated from the EU Water Framework Directive reporting of hydromorphological assessment where the layer includes those pressures which affect the hydrographical conditions.

	Class	Regions								Total	
		Baltic Sea		Black Sea		Mediterranean Sea		NE Atlantic Ocean			
		km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Region	Total area *	466,100		520,100		2,674,900		11,335,100		14,996,200	
	No data	8,800	2 %	80,500	15 %	113,400	4 %	227,000	2 %	429,700	3 %
	No pressure	431,300	93 %	436,600	84 %	2,498,000	93 %	11,055,100	98 %	14,421,000	96 %
	Pressure	26,000	6 %	3,000	1 %	63,500	2 %	53,000	0 %	145,500	1 %
Coastal	Coastal area *	172,900		106,600		439,900		757,600		1,477,000	
	No data	8,800	5 %	,800	1 %	113,400	26 %	227,000	30 %	350,000	24 %
	No pressure	138,300	80 %	103,000	97 %	266,200	61 %	482,400	64 %	989,900	67 %
	Pressure	25,800	15 %	2,800	3 %	60,300	14 %	48,200	6 %	137,100	9 %
Shelf	Shelf area *	293,200		143,100		773,500		3,584,200		4,794,000	
	No data	0	0 %	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	293,000	100 %	142,900	100 %	770,300	100 %	3,579,400	100 %	4,785,600	100 %
	Pressure	200	0 %	200	0 %	3,200	0 %	4,800	0 %	8,400	0 %
Offshore	Offshore area *	0		270,400		1,461,500		6,993,300		8,725,200	
	No data	-	-	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	-	-	270,400	100 %	1,461,500	100 %	6,993,300	100 %	8,725,200	100 %
	Pressure	-	-	0	0 %	0	0 %	0	0 %	0	0 %

*) Note that the area is calculated from the 10 km x 10 km grid cells and overestimates the real geographical area.

Table B9 Hazardous substances: The layer is based on the integrated assessment of contamination status (EEA, 2019b). The coastal status is assessed by using 10 km x 10 km grid cells, but 100 km x 100 km cells were used for the other areas. The indicator information was assumed to be representative for the entire cell area.

	Class	Regions								Total	
		Baltic Sea		Black Sea		Mediterranean Sea		NE Atlantic Ocean			
		km²	%	km²	%	km²	%	km²	%	km²	%
Region	Total area *	466,100		520,100		2,674,900		11,335,100		14,996,200	
	No data	0	0 %	0	0 %	100	0 %	4,267,800	38 %	4,267,900	28 %
	No pressure	246,800	53 %	456,500	88 %	2,560,300	96 %	6,013,600	53 %	9,277,200	62 %
	Pressure	219,300	47 %	63,600	12 %	114,500	4 %	1,053,700	9 %	1,451,100	10 %
Coastal	Coastal area *	172,900		106,600		439,900		757,600		1,477,000	
	No data	0	0 %	0	0 %	100	0 %	168,300	22 %	168,400	11 %
	No pressure	108,500	63 %	99,600	93 %	355,900	81 %	411,200	54 %	975,200	66 %
	Pressure	64,400	37 %	7,000	7 %	83,900	19 %	178,100	24 %	333,400	23 %
Shelf	Shelf area *	293,200		143,100		773,500		3,584,200		4,794,000	
	No data	0	0 %	0	0 %	0	0 %	1,139,900	32 %	1,139,900	24 %
	No pressure	138,000	47 %	99,400	69 %	752,300	97 %	1,607,900	45 %	2,597,600	54 %
	Pressure	155,200	53 %	43,700	31 %	21,200	3 %	836,400	23 %	1,056,500	22 %
Offshore	Offshore area *	0		270,400		1,461,500		6,993,300		8,725,200	
	No data	-	-	0	0 %	0	0 %	2,960,200	42 %	2,960,200	34 %
	No pressure	-	-	257,500	95 %	1,452,100	99 %	3,993,900	57 %	5,703,500	65 %
	Pressure	-	-	12,900	5 %	9,400	1 %	39,200	1 %	61,500	1 %

*) Note that the area is calculated from the 10 km x 10 km grid cells and overestimates the real geographical area.

Table B10 Continuous underwater noise: The layer is based on maritime traffic density.

	Class	Regions								Total	
		Baltic Sea		Black Sea		Mediterranean Sea		NE Atlantic Ocean			
		km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Region	Total area *	466100		520100		2674900		11335100		14996200	
	No data	0	0 %	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	12000	3 %	33000	6 %	77700	3 %	9891500	87 %	10014200	67 %
	Pressure	454100	97 %	487100	94 %	2597200	97 %	1443600	13 %	4982000	33 %
Coastal	Coastal area *	172900		106 600		439900		757 600		1477000	
	No data	0	0 %	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	11900	7 %	23500	22 %	55500	13 %	116400	15 %	207300	14 %
	Pressure	161000	93 %	83100	78 %	384400	87 %	641200	85 %	1269700	86 %
Shelf	Shelf area *	293200		143100		773500		3584200		4794000	
	No data	0	0 %	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	100	0 %	9500	7 %	21000	3 %	135400	4 %	166000	3 %
	Pressure	293100	100 %	133600	93 %	752500	97 %	3448800	96 %	4628000	97 %
Offshore	Offshore area *	0		270400		1461500		6993300		8725200	
	No data	-	-	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	-	-	0	0 %	1200	0 %	336600	5 %	337800	4 %
	Pressure	-	-	270400	100 %	1460300	100 %	6656700	95 %	8387400	96 %

*) Note that the area is calculated from the 10 km x 10 km grid cells and overestimates the real geographical area.

Table B11 Impulsive underwater noise: The layer presents the ICES impulsive noise register and the ACCOBAMS register from the Mediterranean Sea.

	Class	Regions								Total	
		Baltic Sea		Black Sea		Mediterranean Sea		NE Atlantic Ocean			
		km²	%	km²	%	km²	%	km²	%	km²	%
Region	Total area *	466,100		520,100		2,674,900		11,335,100		14,996,200	
	No data	0	0 %	502,100	97 %	500	0 %	2,270,200	20 %	2,772,800	18 %
	No pressure	318,800	68 %	8,500	2 %	2,575,000	96 %	8,972,200	79 %	11,874,500	79 %
	Pressure	147,300	32 %	9,500	2 %	99,400	4 %	92,700	1 %	348,900	2 %
Coastal	Coastal area *	172,900		106,600		439,900		757,600		1,477,000	
	No data	0	0 %	93,600	88 %	300	0 %	100,400	13 %	194,300	13 %
	No pressure	123,900	72 %	12,800	12 %	382,900	87 %	594,400	78 %	1,114,000	75 %
	Pressure	49,000	28 %	200	0 %	56,700	13 %	62,800	8 %	168,700	11 %
Shelf	Shelf area *	293,200		143,100		773,500		3,584,200		4,794,000	
	No data	0	0 %	138,800	97 %	200	0 %	296,700	8 %	435,700	9 %
	No pressure	194,900	66 %	4,300	3 %	531,000	69 %	2,822,200	79 %	3,552,400	74 %
	Pressure	98,300	34 %	0	0 %	242,300	31 %	465,300	13 %	805,900	17 %
Offshore	Offshore area *	0		270,400		1,461,500		6,993,300		8,725,200	
	No data	-	-	269,700	100 %	0	0 %	1,873,100	27 %	2,142,800	25 %
	No pressure	-	-	700	0 %	1,286,500	88 %	5,039,900	72 %	6,327,100	73 %
	Pressure	-	-	0	0 %	175,000	12 %	80,300	1 %	255,300	3 %

*) Note that the area is calculated from the 10 km x 10 km grid cells and overestimates the real geographical area.

Table B12 Microbial pathogens: The layer presents the EEA's Bathing Water Directive reporting.

	Class	Regions								Total	
		Baltic Sea		Black Sea		Mediterranean Sea		NE Atlantic Ocean			
		km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Region	Total area *	466,100		520,100		2,674,900		11,335,100		14,996,200	
	No data	9,400	2 %	50,200	10 %	72,100	3 %	223,000	2 %	354,700	2 %
	No pressure	425,300	91 %	460,400	89 %	2,503,400	94 %	11,019,400	97 %	14,408,500	96 %
	Pressure	31,400	7 %	9,500	2 %	99,400	4 %	92,700	1 %	233,000	2 %
Coastal	Coastal area *	172,900		106 ,600		439,900		757,600		1,477,000	
	No data	9,400	5 %	50,200	47 %	72100	16 %	223,000	29 %	354,700	24 %
	No pressure	152,300	88 %	54,200	51 %	334,000	76 %	502,200	66 %	1,042,700	71 %
	Pressure	11,200	6 %	2,200	2 %	33,800	8 %	32,400	4 %	79,600	5 %
Shelf	Shelf area *	293,200		143,100		773,500		3,584,200		4,794,000	
	No data	0	0 %	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	273,000	93 %	136,300	95 %	718,300	93 %	3,528,700	98 %	4,656,300	97 %
	Pressure	20,200	7 %	6,800	5 %	55,200	7 %	55,500	2 %	137,700	3 %
Offshore	Offshore area *	0		270,400		1,461,500		6,993,300		8,725,200	
	No data	-	-	0	0 %	0	0 %	0	0 %	0	0 %
	No pressure	-	-	269,900	100 %	1,451,100	99 %	6,988,500	100 %	8,709,500	100 %
	Pressure	-	-	500	0 %	10,400	1 %	4,800	0 %	15,700	0 %

*) Note that the area is calculated from the 10 km x 10 km grid cells and overestimates the real geographical area.

Table B13 Species disturbance due to human presence: The pressure presents areas of human presence based on coastal population density as well as spatial layers of urban land use.

	Class	Regions								Total	
		Baltic Sea		Black Sea		Mediterranean Sea		NE Atlantic Ocean			
		km²	%	km²	%	km²	%	km²	%	km²	%
Region	Total area *	466,100		520,100		2,674,900		11,335,100		14,996,200	
	No data	15,100	3 %	51,700	10 %	83,400	3 %	1,549,500	14 %	1,699,700	11 %
	No pressure	380,300	82 %	444,600	85 %	2,423,700	91 %	9,585,900	85 %	12,834,500	86 %
	Pressure	70,700	15 %	23,800	5 %	167,800	6 %	199,700	2 %	462,000	3 %
Coastal	Coastal area *	172,900		106,600		439,900		757 ,600		1,477,000	
	No data	9,300	5 %	51,000	48 %	81,200	18 %	188,800	25 %	330,300	22 %
	No pressure	93,800	54 %	31,900	30 %	193,100	44 %	371,200	49 %	690,000	47 %
	Pressure	69,800	40 %	23,700	22 %	165,600	38 %	197,600	26 %	456,700	31 %
Shelf	Shelf area *	293,200		143,100		773,500		3,584,200		4,794,000	
	No data	5,800	2 %	700	0 %	500	0 %	2,700	0 %	9,700	0 %
	No pressure	286,500	98 %	142,300	99 %	771,300	100 %	3,579,800	100 %	4,779,900	100 %
	Pressure	900	0 %	100	0 %	1,700	0 %	1,700	0 %	4,400	0 %
Offshore	Offshore area *	0		270,400		1,461,500		6,993,300		8,725,200	
	No data	-	-	0	0 %	500	0 %	0	0 %	,500	0 %
	No pressure	-	-	270,400	100 %	1,460,600	100 %	6,992,900	100 %	8,723,900	100 %
	Pressure	-	-	0	0 %	400	0 %	400	0 %	800	0 %

*) Note that the area is calculated from the 10 km x 10 km grid cells and overestimates the real geographical area.

Table B14 Sea surface temperature (SST) anomalies: The anomalies in SST over Europe's sea area

	Class	Regions								Total	
		Baltic Sea		Black Sea		Mediterranean Sea		NE Atlantic Ocean			
		km²	%	km²	%	km²	%	km²	%	km²	%
Region	Total area *	466,100		520,100		2,674,900		11,335,100		14,996,200	
	No data	168,500	36 %	81,600	16 %	181,900	7 %	1,549,500	14 %	1,981,500	13 %
	No pressure	0	0 %	0	0 %	0	0 %	0	0 %	0	0 %
	Pressure	297,600	64 %	438,500	84 %	2,493,000	93 %	97,85,600	86 %	13,014,700	87 %
Coastal	Coastal area *	172,900		106,600		439,900		757,600		1,477,000	
	No data	92,600	54 %	41,700	39 %	102,500	23 %	172,600	23 %	409,400	28 %
	No pressure	0	0 %	0	0 %	0	0 %	147,400	19 %	147,400	10 %
	Pressure	80,300	46 %	64,900	61 %	337,400	77 %	437,600	58 %	920,200	62 %
Shelf	Shelf area *	293,200		143,100		773,500		3,584,200		4,794,000	
	No data	75,900	26 %	33,600	23 %	56,000	7 %	885,900	25 %	1,051,400	22 %
	No pressure	0	0 %	0	0 %	0	0 %	0	0 %	0	0 %
	Pressure	217,300	74 %	109,500	77 %	717,500	93 %	2,698,300	75 %	3,742,600	78 %
Offshore	Offshore area *	0		270,400		1,461,500		6,993,300		8,725,200	
	No data	-	-	6,300	2 %	23,400	2 %	343,600	5 %	373,300	4 %
	No pressure	-	-	0	0 %	0	0 %	0	0 %	0	0 %
	Pressure	-	-	264,100	98 %	1,438,100	98 %	6,649,700	95 %	8,351,900	96 %

*) Note that the area is calculated from the 10 km x 10 km grid cells and overestimates the real geographical area.

Appendix C. Assessment method and ecosystem sensitivity scores

Technical steps needed for a cumulative effect assessment

The method for a spatial assessment tool for cumulative pressures and potential effects can be presented by a concise, step-wise method description. For further technical details, one can consult, for instance, Andersen & Stock (2013).

- Definition of the assessment area: prepare a GIS file of the area where the assessment will be made. The final GIS file can be either a vector polygon or a raster.
- Listing and defining human activities and consequent pressures in the area: List all human activities and their pressures in the area and link those to each other.
- Listing and defining receptors (e.g. ecosystem components) in the area: if the assessment will include impacts on ecosystem, then also the ecosystem data will be needed. Identify habitats, functional habitats, keystone species or functional groups, which are ecologically most important for the assessment area.
- Decisions on time scales: there will be two separate decisions related to time: (1) what will be the assessment period (→ data collection period) and (2) will there be seasonal (or even more detailed) impacts on the assessment. Especially the latter may require careful consideration. For instance, pressures and impacts on seabirds may be entirely different in the breeding, migration or wintering time. Moreover, a pressure may occur only in the summer period (e.g. tourism), autumn period (e.g. seabird hunting) or spring period (e.g. muddy riverine plumes).
- Collecting the spatial data for the entire assessment area: based on the lists in steps 2 and 3, collect spatial data. The data must cover the entire assessment area. Sometimes the pressure data may need to be estimated from human activity data. If pressures are quantified (recommended), then the data should be in the same metric. The ecosystem data can be either on the presence/absence scale (especially for habitats) or on the probability scale (especially for species).
- Preparation of the GIS files: Make the GIS layers for the pressures and the ecosystem components. Consider especially how widely a pressure can spread from the source. This is usually to the same extent as to how widely the impacts occur. Note that this extent differs among the sources. For instance, a plume of waterborne nutrient input depends on the water outflow from a river or a point source. Note that some attenuation of the pressure will happen, and its form should be considered (linear, logarithmic, etc.).
- Aggregation of pressure data layers: look critically at the pressure data in order to see whether it is in balance. Pressure data may need aggregation if several pressure GIS-layers describe the same pressure or human activity. For example, fishing data for all the gear types would overweigh the fishing pressure. In such cases, the layers need to be aggregated.
- Definition of the assessment unit: based on the spatial resolution of the input data, define the size and shape of the assessment units. The shape is usually a square but also hexagon or any other shape can be defined. In principle the sizes can vary but in practice a grid of similar-sized units is used. The unit size depends on the input data: coarse input data to a detailed grid may give an over-positive message, while detailed input data will be masked by two coarse assessment units. In practice, also the scale of the assessment area affects this decision: assessments on the scale of a regional sea do not usually have spatially detailed data from all the countries and might therefore have a unit size of 1–25 km^2 while smaller scales should aim at a maximum of 1 km^2 unit sizes.

- Estimation of impact weights: impact weight scores have usually been estimated on the basis of expert judgement. This has been seen to be justified as the impacts are usually very complicated and the weight scores should comprise similar elements such as the magnitude of the impact (e.g. chronic, acute, devastating), extent in the ecosystem (e.g. a single species, a community, several trophic levels), recovery from the impact (e.g. fast, a year, a few years, decades).
- Calculating the index: the assessment will be based on several data layers and these should be repeatedly run to get several assessment outcomes. Although this can be done even on Excel, a software or script is recommended.
- Outcomes of the index: the index results are usually presented in cartographic form, but also various graphs can be produced. In addition, the index can be calculated for separate activities, pressures or receptors.

Table C1. Sensitivity scores used in the cumulative effect assessment. The scores are median values of all the expert responses. See Chapter 4.1 and Appendix C text for description.

	Circalittoral coarse sediment	Circalittoral mixed sediment	Circalittoral mud	Circalittoral rock and biogenic reef	Circalittoral sand	Infralittoral coarse sediment	Infralittoral mixed sediment	Infralittoral mud	Infralittoral rock and biogenic reef	Infralittoral sand	Offshore circalittoral coarse sediment	Offshore circalittoral mixed sediment	Offshore circalittoral mud	Offshore circalittoral rock and biogenic reef	Offshore circalittoral sand	Bathyal	Abyssal	Small toothed cetaceans	Deep diving toothed cetaceans	Baleen whales	Seals	Turtles	Breeding birds	Fish	Saltmarshes	Seagrasses	Cold-water corals and other coralligenous formations	Seamounts	Coastal water column habitat	Offshore water column habitat
BALTIC SEA																														
Introductions of non-indigenous species	3	3	2,63	3	2,75	3	3	3	3	2,63	2,75	2,5	2,25	3	2,5			1			1,5		2	2	2,13	2,88	3,75	2,5	3	3
Input of microbial pathogens	3	3	3	2	2,5	2	2,5	2,5	2	2,5	2,5	2,5	2,5	2,5	2,5			4			3,5		3,5	4	2	2	2	1,5	2,5	2,5
Disturbance of species due to human presence	1	1	1	1,5	1	2	2	2	2	2	0	0	0	1	0			3			3,13		4	2	2,75	2	1,5	0	2	0
Extraction of species by commercial fishing	1	1	1	2	1	2	2	2	2	2	1	1	1	2	1			2			2		2	4,63	0	1,5	2	4	3	3
Bycatch by pelagic towed gear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			3			2		2,5	4	0	0	1	2	3	3
Bycatch by bottom touching mobile gear	3,5	3,5	3	3	3,5	2	2	3	3	3	4	4	4	3	4			1			1		1	4	0	2	2,5	3,5	1	1
Physical loss of seabed	5	5	5	5	5	5	5	5	5	5	4,75	4,75	4,5	5	4,75			2			1,5		1	3	5	5	5	4,5	1	1,13
Physical disturbance to seabed	3,25	3	4	4	4	3	3	4	4	4	3,13	3	4	4	3,5			1			1		1	3	4	4	3,5	3,5	2	0
Changes to hydrological conditions	2	2	2	2	2	2,38	2,38	2,38	3	2,13	2	2	2	2	2			0,5			1		1	2,75	3	3,5	2,5	1	2	3
Inputs of nutrients	3	3	3	3,13	3	3,63	3	3,13	4	3,63	3	3	3	3	3			1,5			1,5		2	3	4	4,88	3	2	4	4
Input of organic matter	3	3	3	3	3	4	4	3	4	3	2,5	2,5	2,5	3	2,5			1			1		2	2	2	3	3	1,5	4	2,5
Input of hazardous substances	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3			4			4		4	4	3	3	2,5	2,5	2,5	2,5
Input of continuous anthropogenic sound	0,5	0,5	0,5	0,5	0,75	0,88	0,88	0,88	0,75	0,88	0	0	0	0	0			4			3,38		3	3	0,75	0,5	1	0	1	0
Input of impulsive anthropogenic sound	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,75	0,88	0,75	0,75	0,75	0,75	0,75			4,88			4		4	3	0,75	0,63	1	0	1,75	2
Global change	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	4	3,5	3	3	3	3	3			2			3		2	3	3,5	3	3	2,5	4	4

	Circalittoral coarse sediment	Circalittoral mixed sediment	Circalittoral mud	Circalittoral rock and biogenic reef	Circalittoral sand	Infralittoral coarse sediment	Infralittoral mixed sediment	Infralittoral mud	Infralittoral rock and biogenic reef	Infralittoral sand	Offshore circalittoral coarse sediment	Offshore circalittoral mixed sediment	Offshore circalittoral mud	Offshore circalittoral rock and biogenic reef	Offshore circalittoral sand	Bathyal	Abyssal	Small toothed cetaceans	Deep diving toothed cetaceans	Baleen whales	Seals	Turtles	Breeding birds	Fish	Saltmarshes	Seagrasses	Cold-water corals and other coralligenous formations	Seamounts	Coastal water column habitat	Offshore water column habitat
BLACK SEA																														
Introductions of non-indigenous species	2	2	2	2	2	3	3	3	3	3	1	1	1	1	1	0	0	0	2	2	0	1	0,5	3	4	3,5	4	1	3	2
Input of microbial pathogens	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	0,63	0,63	1,81	3	3		0,63	0,81	2,81	4	3	4	2	4	0,31
Disturbance of species due to human presence	2	2	2	2	2	4	4	4	4	4	1	1	1	1	1	0	0	3,41	4	4	4	3,41	4,5	2,16	5	4	5	1	0	0
Extraction of species by commercial fishing	3	3	3	3	3	5	5	5	4	5	5	5	5	3	5	2	0	4,5	4	4	4	4,5	4	5	3	2,5	3	3	5	2
Bycatch by pelagic towed gears	4	4	4	2	4	5	5	5	3	4	4	4	4	3	4	3,5	2,5	4	4	4	3	4,5	3	5	2	2	1	1	0	0
Bycatch by bottom touching mobile gear	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3	2	2	2	3,5	2,5	4	4	5	5	5	2	0
Physical loss of seabed	2,41	2,77	2,77	2,41	3,27	3,27	3,27	3,27	3,27	3,27	2,41	2,77	2,77	1,91	2,27	3,18	3,18	1,81	3	3	3	1,81	0,81	2,81	5	4	5	5	2	2
Physical disturbance to seabed	1	1,5	2	1	2	3	3	3,5	2	3,5	0,81	0,81	1,81	0,81	1,31	0,63	0,63	2	3	3	3	1,53	0,53	2	5	5	5	5	2	0,63
Changes to hydrological conditions	2	2	2	2	2	4	4	4	4	4	0,63	0,63	0,63	0,63	0,63	0,63	0,63	1,53	3	3	5	2,03	1	2,53	5	4,5	5	5	3	0,31
Inputs of nutrients	2	2	2	2	2	4	4	4	4	4	1	1	1	1	1	1	0,63	1,5	3	3	3	1,5	1	2,81	5	4,5	5	2	4	1
Input of organic matter	2	2	2	2,81	2	2	2	2	2	1	1,81	1,81	1,81	1,81	1,81	1,81	0,63	1	2	2	2	1	1	2,81	4	3,5	3	2	3	0,63
Input of hazardous substances	2,81	2,81	2,81	2,81	2,81	5	2,81	2,81	5	2,81	1,81	1,81	1,81	1,81	1,81	1,81	1,31	2,81	5	5	5	2,81	2,81	2,81	5	5	5	5	3	0,31
Input of continuous anthropogenic sound	2	2	2	2	2	2	1	1	2	1	1	1	1	1	1	1	1	2,63	5	5	5	2,63	2	2,14	4	4	4	2	2	2
Input of impulsive anthropogenic sound	2	2	2	2	2	2	1	1	2	1	1	1	1	1	1	1	1	2,63	5	5	5	2,63	1	2,14	4	4	4	2	2	3
Global change	1,81	1,81	1,81	1,81	1,81	1,81	1,81	1,81	3	1,81	1,81	1,81	1,81	1,81	1,81	1,81	0,81	1,5	3	3	3	1,5	1,5	1,53	3	3	3	1	3,5	3

	Circalittoral coarse sediment	Circalittoral mixed sediment	Circalittoral mud	Circalittoral rock and biogenic reef	Circalittoral sand	Infralittoral coarse sediment	Infralittoral mixed sediment	Infralittoral mud	Infralittoral rock and biogenic reef	Infralittoral sand	Offshore circalittoral coarse sediment	Offshore circalittoral mixed sediment	Offshore circalittoral mud	Offshore circalittoral rock and biogenic reef	Offshore circalittoral sand	Bathyal	Abyssal	Small toothed cetaceans	Deep diving toothed cetaceans	Baleen whales	Seals	Turtles	Breeding birds	Fish	Saltmarshes	Seagrasses	Cold-water corals and other coralligenous formations	Seamounts	Coastal water column habitat	Offshore water column habitat
MEDITERRANEAN SEA																														
Introductions of non-indigenous species	3	3	3	4	3	3	3	3	4	3	1	1	1	2	1	0	0	0,5	0	0,5	0	2,5	1	4	3	4	3	0	4	2,5
Input of microbial pathogens	1	1	1	3	1	3	2,5	2,5	2,5	2,5	0	0	0	0	0	0	0	2,5	1,5	2	3,5	4	2	3	3	3,5	1	0	2,5	2
Disturbance of species due to human presence	2,5	2,5	2,5	3	2,5	4	3,5	2	4	4	1	1	1	2	1	1	0	3	3	2	5	4	5	3,5	4	4	2	1	3	2
Extraction of species by commercial fishing	4	4	4	4	4	3,5	4	3	3	4	4	4	4	4	4	3,5	2	4	3	3	4	4	3	5	2	3,5	4	3	4	4
Bycatch by pelagic towed gear	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0,5	0	3	3	3	3	4	3	5	0	2	1,5	0	4	4
Bycatch by bottom touching mobile gear	4,5	4,5	4	4	4,5	3	3	3	3	3	5	4,5	4,5	4	4,5	4	1	2	2	1,5	3	3,5	1	5	0,5	5	4,5	3	1,5	2
Physical loss of seabed	3	3	3	4	3	4	4	4	4,5	4	3	2,5	2,5	3	2,5	2,5	2,5	1	1	1	3	2,5	3	3,5	4,5	5	4	1	2	1
Physical disturbance to seabed	4	3,5	3,5	4	3,5	4	4	4	5	4	3	3	4	4	3	3	2	1,5	1	1	4	1,5	3	4	4,5	5	4	1	3,5	2
Changes to hydrological conditions	3	3	3	3	3	4	4	3	4,5	4	3	3	2	3	2	1	1	1	1	1	3,5	2	2,5	3,5	5	5	3	0,5	4	2,5
Inputs of nutrients	2	2	3	3	3	3	3	2	4	3,5	1,5	1	1	2,5	1,5	1	0	1	1	1	3	2	2	3	4	4	3	0	3,5	2
Input of organic matter	2	2	2,5	3	2,5	3,5	3	3	4	3	1	1	1	2	1	0	0	1	0	0,5	2,5	1	1,5	3	4	4	3	0	3,5	2
Input of hazardous substances	3	3	3	3	3	3	3	3,5	3	3	3	3	3	3	3	3	2,5	4	4	4	4,5	4	4	4	4	3	3	2	3	3
Input of continuous anthropogenic sound	0	0	1	1,5	1	0	0	1	1,5	0	0	0	0	1,5	0	0	0	5	5	5	4,5	4	4	4	0	0	0,5	0	3,5	3
Input of impulsive anthropogenic sound	0	0	0	1,5	0	0	0	0	1,5	0	0	0	0	1,5	0	0	0	5	5	5	4,5	4	4	4	0,5	0	1	0	4	3
Global change	3	2,5	2,5	4	2,5	3	2,5	2,5	5	3	2	2	2	3	2	2	2	3	3	4	4	5	4	4	4,5	4	4,5	3		3

	Circalittoral coarse sediment	Circalittoral mixed sediment	Circalittoral mud	Circalittoral rock and biogenic reef	Circalittoral sand	Infralittoral coarse sediment	Infralittoral mixed sediment	Infralittoral mud	Infralittoral rock and biogenic reef	Infralittoral sand	Offshore circalittoral coarse sediment	Offshore circalittoral mixed sediment	Offshore circalittoral mud	Offshore circalittoral rock and biogenic reef	Offshore circalittoral sand	Bathyal	Abyssal	Small toothed cetaceans	Deep diving toothed cetaceans	Baleen whales	Seals	Turtles	Breeding birds	Fish	Saltmarshes	Seagrasses	Cold-water corals and other coralligenous formations	Seamounts	Coastal water column habitat	Offshore water column habitat
NE ATLANTIC OCEAN																														
Introductions of non-indigenous species	3	3	3	3	3	2	2	2	3	2	2	2	2	2	2	2	2	0,5	0	0	0	0	1	1,5	2,5	3	3	1	3	2
Input of microbial pathogens	1,5	2	1,5	1,5	1,5	1	1	1	1,5	1	0,31	0,31	0,81	0,31	0,31	0	0	1	1	1	1	1,5	1,5	2	1	2	1	0	1,5	1
Disturbance of species due to human presence	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	2,91	2,81	2,81	3	3	3	2	2,5	3	1	0	1	0
Extraction of species by commercial fishing	3	2,5	3,5	3	3	3	3	3,5	3,5	3	3	2,5	4	3	3,5	2	2	3	2	2	3	2	3	4,5	0,5	1	1	1,5	1,5	2
Bycatch by pelagic towed gear	0,5	0,5	0,5	0,5	0,5	0	0,5	0,5	0,5	0,5	1	0,5	0,5	1	0,5	0	0	4	3	2	2,5	4	3	3,5	0	0	1	1	3	3
Bycatch by bottom touching mobile gear	2	2,5	3	3,5	3	2	2,5	3	3	3	2	2,5	3	3	2,5	2,5	2	2,5	2	0,5	1,5	2	0	3	0	1,5	3	3	0	0
Physical loss of seabed	2,91	2,27	2	4	2	3	2,5	2	4	2	1,5	1,5	1	4	2	1	1	0,63	0	0	0	0,31	0,81	2	3	4	4	4	0	0
Physical disturbance to seabed	2,5	2,5	2,5	3	2	2	2,5	2	4	2,5	2	2,5	3	3	2	1	1	0,05	0,05	0	0,05	1,03	0,03	1	2	4	4	3	0,31	0
Changes to hydrological conditions	1,5	1	1,5	1,5	1	3	2	3	3	2	1,5	1	1	1	1	1	1	0,03	0,03	0,03	0,03	0,05	1	2	2,5	4	3	0	2	1
Inputs of nutrients	2	2	2	2	2	2	2	2,5	2,5	2	1,5	1,5	1,5	2	1,5	1	1	0	0	0	0	0,5	2	2,5	4	4	3	1	4	3
Input of organic matter	2	2	2	2	2	2	2	2,5	2,5	2	1,5	1,5	1,5	2	1,5	0,81	1	0	0	0	0	1	1	1	2	3	2,5	1,5	2,5	1
Input of hazardous substances	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1	1	1,5	1	1	1	1	3	3	3	3	3,5	3	3	2	2	1	1	2	2
Input of continuous anthropogenic sound	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	3,5	3,5	3,5	2,5	2	1	2	0	0	0	0	1	1
Input of impulsive anthropogenic sound	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4,5	4,5	4,5	3,5	2	3	3	0	0	0	0	1	1
Global change	1	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	1	2	3	3	2	3,5	2,5	3	4	4	3	2,5	4	4

Appendix D. Europe's seas contribution to the lives of EU citizens

Marine natural capital is a concept to encourage the wise use of the wealth that the sea makes available to people

People depend on marine biota, marine ecosystems and marine non-living resources to fulfil their basic needs, and for their well-being, livelihoods and economy (MA, 2005; Maes et al., 2013; EEA, 2015a, b; IPBES, 2018, 2019). From providing us with food, building materials, medicines, energy and opportunities for leisure, to limiting the erosion of our coasts and the pollution of seawater - a lot of what we consume, use or enjoy in our daily lives comes from the sea, whether we realise it or not. This wealth is the sea's contribution to the 'natural capital', which is just a label to make the dependence of people on nature and natural assets explicit. Such a label is especially important in the context of a country's economic output, which does not just rely on other types of capital, i.e. manufactured, human, social and financial (Pearce at al., 1989; EEA, 2015a, Culhane et al., 2019).

Natural capital has two constituents: biotic natural capital, better known as ecosystem capital, and abiotic (i.e. non-living) natural capital (Maes et al., 2013; EEA 2015a; Jones et al, 2015; Culhane et al., 2019). *Marine* natural capital refers to the application of the natural capital concept in a marine setting and it is, thus, also made up of these two constituents (Figure D1), where:

- Marine *ecosystem* capital refers to marine ecosystems as assets and comprises marine ecosystem 'stocks' and the 'flows' of marine ecosystem services they generate, and which provide benefits to people. 'Ecosystems' encompass the ecological structures, namely marine biota and their outputs[3], habitats[4] and physico-chemical elements[5], as well as the ecological processes and functions, which refer to the interactions amongst marine biota and between them and their non-living environment (CBD, 2004). All these interactions are made possible by marine biological diversity, which is what underpins the capacity of marine ecosystems to supply marine ecosystem services.
- Marine *abiotic* natural capital refers to abiotic natural assets available in the marine environment. It comprises the stocks and flows of non-living marine resources, such as seawater, salt and geological deposits of minerals, sand and gravel, fossil fuels; assets linked to geophysical cycles, such as solar radiation, wind and currents; as well as the tides.

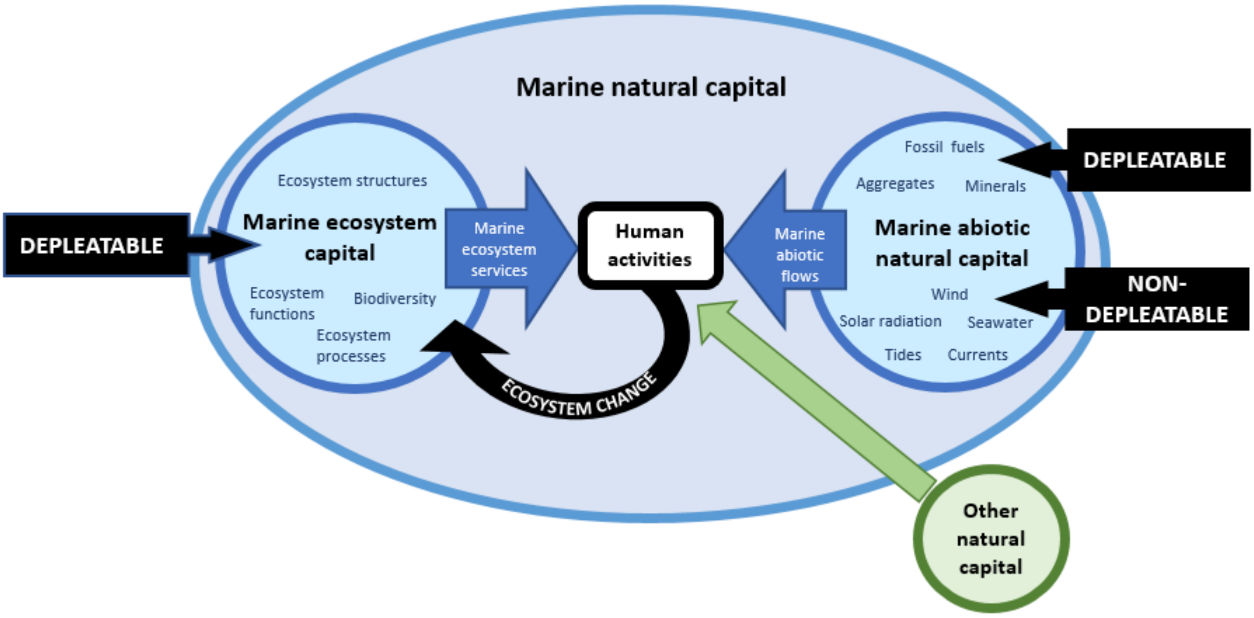
In reality, however, there is no clear-cut boundary between the 'biotic' and 'abiotic' constituents of marine natural capital because, e.g., sand is the substrate of many marine habitats (ecosystem structures). However, this distinction helps to identify and classify such categories, which is important in the context of assessing the condition of marine ecosystems and managing human activities using marine natural capital. Nevertheless, a key difference between them is that marine ecosystem capital is, ultimately, depletable and marine abiotic natural capital can be depletable or not (Maes et al., 2013; EEA 2015a; Culhane et al., 2019) (Figure D1). Marine ecosystem capital is depletable because the human activities using, both the ecosystem and abiotic constituents of, marine natural capital, as needed to run our socio-technical systems, can degrade and, eventually, deplete marine ecosystems if this use does not respect their ecological limits.

[3] Outputs from marine biota are, e.g., shells, seagrass peat, and ambergris.

[4] Marine habitats here refer to biotopes, i.e. comprising both biological, e.g. macroalgae, and physical, e.g. benthic substrates such as rock and sand, components.

[5] The physico-chemical elements of marine ecosystems include light, dissolved carbon and nutrients.

Figure D1: The constituents of marine natural capital



Notes:

- Marine ecosystems (*sensu* CBD, 2004) and their services, fossil fuels, aggregates, minerals and any other geological deposits are depleatable. Seawater, salt, tides and geophysical assets, such as wind, currents and global solar radiation (which is constant above the atmosphere and hence considered a stable asset) are non-depletable.
- 'Ecosystem change' refers to the physical, chemical and biological impacts on marine ecosystems resulting from human activities drawing on marine, and other, natural capital.
- 'Other natural capital' refers to that held in terrestrial and freshwater environments.

Source: Modified from the EEA (2015a) and Culhane et al. (2019)

Marine ecosystem services are the direct contributions from marine ecosystems to people

Marine ecosystem services represent the flows of marine ecosystem capital that are realised because of human active or passive demand (Figure D1). This demand is linked to the fact that ecosystem services provide a series of important benefits[6], such as nutrition and enhanced physical, mental and emotional health (Culhane et al., 2019) (Box D1).

Some of these service flows make marine ecosystem capital the most fundamental form of marine natural capital because they contribute to enabling the basic conditions for human existence and to human well-being (EEA 2015a; 2015b; Culhane et al., 2019) – even if that may not always be obvious to people. For example, marine ecosystem services relating to:

- Seafood, e.g. fish and shellfish; clean seawater, through, e.g., macro algae treating our organic wastes; and oxygen supply, a by-product of macro/micro-algae and marine plant photosynthesis, all support people's existence. Thus, e.g., the sea provides about 50 % of the oxygen in the air we breathe (Lalli & Parsons, 1993; Behrenfeld et al., 2001). This constitutes the *Oxygen production* marine ecosystem service, which we use passively, and which keeps us alive (benefit) (Figure D2) (Culhane et al., 2019).

[6] Obtaining the benefits from services for which there is an *active* human demand requires human inputs (such as labour, capital, or energy investments, Maes et al., 2013). The benefits from services for which there is a *passive* human demand are, in principle, free flowing without requiring human input, but in economic terms there are at least opportunity costs or costs of degradation involved (HM Government, 2012; Maes at al., 2013).

- Disease prevention and control as well as climate regulation contribute to people's well-being. Thus, e.g. the sea, including through its uptake via macro/micro-algae and marine plant photosynthesis, has absorbed about 30 % of the CO_2 emitted to the atmosphere from the burning of fossil fuels and other human activities (IPCC, 2013; Gruber et al, 2019[7]). This constitutes the *Global climate regulation* marine ecosystem service, which we also use passively, and which has helped to mitigate the effects of the climate crisis and to provide us with a habitable ambient climate (benefit) (Figure D2) (Culhane et al., 2019).

Marine ecosystem services are actually defined as the *final* outputs from marine ecosystems that are *directly* consumed, used or enjoyed by people[8] (Fisher et al., 2009; Haines-Young & Potschin, 2013, 2016, 2018; Maes et al., 2013; EEA, 2015a). This definition fits with the Common International Classification of Ecosystem Services (CICES[9]), which is the reference framework for ecosystem services used in EU policy (see, e.g., Maes et al., 2013).

Marine biota is what, ultimately, holds the capacity of marine ecosystems to supply marine ecosystem services which are normally generated through a cascade of interactions (Maes et al., 2013; Haines-Young & Potschin, 2013; EEA, 2015a; Culhane et al., 2019). This cascade starts with marine biota in their habitats, as part of the ecosystem's structures; flows down the processes and functions that these biotas carry out within the ecosystem (Figure D2); and is influenced by marine biodiversity. However, rather than relying on the whole cascade, the ecosystem capacity to supply some services can be held by just marine biota acting as ecosystem structures (Table D1) (Culhane et al., 2019), which is also influenced by marine biodiversity, e.g. genetic diversity (Maes et al., 2013; EEA, 2015a; Heiskanen et al, 2016).

It follows that the generation of marine ecosystem services depends on the *effective* capacity of marine ecosystem to do so, which, in turn, depends on their condition. In principle, a 'good' condition of marine ecosystems implies that they possess the full range of ecosystem structures and interactions involved in service generation. Thus, such a range is taken to represent a good capacity for the supply of ecosystem services[10] and the chance for this capacity to be sustained over time (Borja et al., 2013; Maes et al., 2013; EEA, 2015a; Maes et al, 2018; Culhane et al., 2019). To note, however, that the concept of ecosystem services is anthropocentric in nature, given that ecosystems have the capacity to supply ecosystem services, regardless of whether those services are utilised (active or passively) by people or not (Maes et al., 2013; EEA, 2015a; Culhane et al., 2019).

Unlike the MA (2005) and related classifications, CICES only considers three service categories: Provisioning, Regulation and maintenance, and Cultural ecosystem services. These have a specific meaning when considering their application to marine ecosystems (Table D1). There are 44 marine ecosystem services as established by Culhane et al. (2019) based on version 5.1 of CICES (Figure D1).

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[7] This is 31 % of all anthropogenic CO_2 emitted over 1994–2007.

[8] In contrast, *intermediate* services are only *indirectly* consumed/used/enjoyed by people and can themselves support many other *final* ecosystem services. Therefore, care must be taken to avoid the 'double assessment' of (final and intermediate) services in a services assessment, or the 'double counting' of the benefits from (final and intermediate) services in the economic valuation of service benefits and/or in the monetary accounting of ecosystem services (i.e. the benefit of the final and that/those of the intermediate service/s making it possible). However, there has been much debate in the field of ecosystem services as to what should be described as a 'final' or 'intermediate service' and different service classifications may diverge; although it has also been clarified that this is contextual and that CICES should be seen as being about 'potential final services' (Haines-Young & Potschin, 2016).

[9] https://cices.eu/

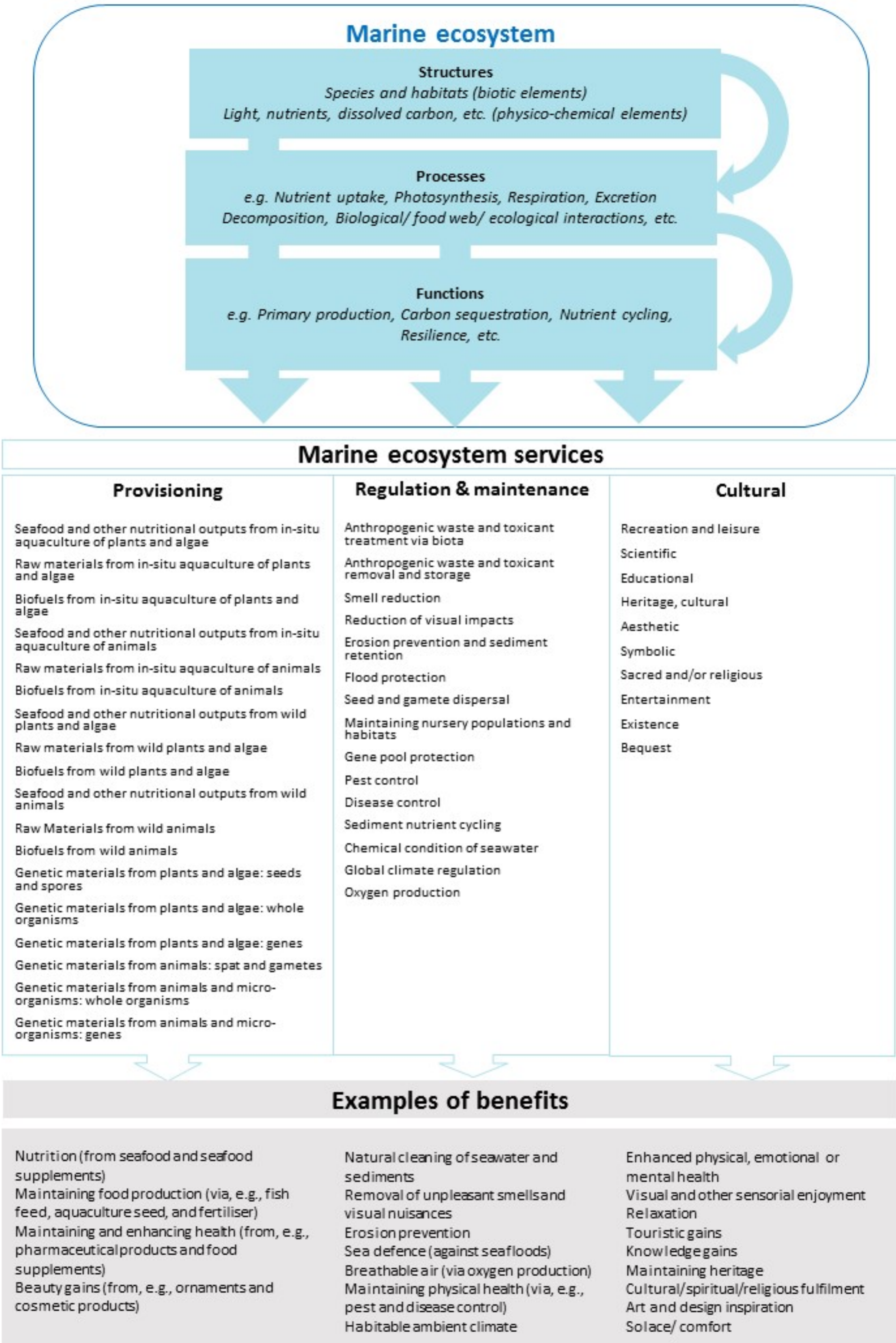
[10] To note, however, that 'good' ecosystem condition does not always equal a 'good' capacity to supply ecosystem services, and vice versa. For example, the *early* stages of eutrophication, i.e. nutrient enrichment, imply a 'not good' state of the ecosystem *sensu* the MSFD (and similarly under the WFD), but a'good'state of service supply capacity because, e.g., phytoplankton is thriving through the removal (from the water column) and storage (in its body) of those nutrients via primary production. Therefore, the actual relationship between ecosystem condition and service generation needs to be established for each marine ecosystem service (Culhane et al., 2019).

Table D1 Categories of marine ecosystem services, their description, and what holds the ecosystem capacity to supply them

Marine ecosystem service category	What holds the ecosystem capacity to supply the services?
Provisioning	
Provisioning marine ecosystem services are all biota and biotic materials constituting tangible outputs from marine ecosystems. They can be exchanged or traded as well as consumed, as foodstuffs (e.g. fish) or used by people in, e.g., manufacturing and the production of energy	Marine biota (their biomass or other biotic outputs, e.g. shells) acting as 'ecosystem structures' is what holds the capacity to supply these services. For example, a wild fish, as an ecosystem structure in itself, holds the capacity to supply the *Seafood and other nutritional outputs from wild animals* service (Figure D2)
Regulation and maintenance	
Regulation and maintenance marine ecosystem services are all the ways in which marine biota and ecosystems control or modify the biotic and abiotic parameters defining the environment of people (i.e. all aspects of the 'ambient' environment). These marine ecosystem outputs are not consumed, but they affect the performance of individuals, communities and populations.	The 'processes' and 'functions' that marine biota carry out within the ecosystem tend to be what holds the capacity to supply these services. For example, the filtration of waste nutrients by benthic invertebrates, such as mussels, holds the capacity to supply the *Anthropogenic waste and toxicant treatment via biota* service. However, there are some instances where this capacity is held in marine biota (their physical presence) acting as 'ecosystem structures'. For example, macroalgae, such a kelp forest, being in place and breaking the energy of waves before they reach the shore, hold the capacity to supply the *Erosion prevention and sediment retention* service (Figure D2). Marine biota and/or ecosystem processes/functions: • Can mediate (neutralise or remove) waste and toxic substances that result from human activities, and this mediation has the effect of detoxifying the marine environment. • Contribute to maintaining coastal landmasses and water currents, reducing, e.g. the intensity of floods and preventing erosion. • Contribute to the provision of sustainable human living (i.e. physical, chemical and biological) conditions.
Cultural	
Cultural marine ecosystem services include all non-material marine ecosystem outputs that have physical, experiential, intellectual, representational, spiritual, emblematic, or other cultural significance.	Marine biota (e.g., their physical presence, existence, image) acting as 'ecosystem structures' tends to be what holds the capacity to supply these services. For example, the capacity to supply the *Existence* service is held by all marine biota (and their habitats) and reflects an intrinsic value of marine biodiversity. However, there are some instances where this capacity is held in ecosystem 'processes' or 'functions' involving certain biotic groups. For example, the sea smell is a by-product of the metabolism of phytoplankton, under certain conditions, or of bacteria when these degrade phytoplankton (Dodd, 2008), which can enhance human physical and intellectual interactions with marine biota/ecosystems linked to using the *Recreation and leisure*-service (Figure D2). Marine biota and/or ecosystem processes/functions: • Can underpin or enhance recreation and leisure, as well as underpin intellectual, cultural, emotional, and artistic development that can depend on a particular condition of marine biota/ecosystems (or where this can enhance it). • Can underpin spiritual development and aspects of legacy, as well as act as cultural or other symbols and have an intrinsic value for people, which can depend on a particular condition of marine biota/ecosystems (or where this can enhance it).

Note: Based on a marine interpretation of the meaning of the 'divisions' and 'sections' within the hierarchy of the Common International Classification of Ecosystem Services (CICES). **Source:** Modified from the EEA (2015a), Maes et al. (2013) and Haines-Young & Potschin (2013, 2018) using Culhane et al. (2019).

Figure D2: Marine ecosystem services and examples of their benefits for people



Note: Marine ecosystem services based on the ecosystem (biotic) service 'classes' in the hierarchy of the Common International Classification of Ecosystem Services (CICES) version 5.1; original service names have been simplified and adapted to a marine context where needed. **Source:** Modified from the EEA (2016) using Culhane et al. (2019).

As was the case with 'natural capital', 'ecosystem services' is also a label to make such biotic flows, i.e. our dependency on ecosystems, explicit. It can, thus, serve to translate the condition of ecosystems into what that means to people in terms of contributions to, and benefits for, their lives, living conditions, livelihoods and economy, which can be kept, gained or lost (Figure D2).

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Appendix E. Cumulative IMPact of marine ALien species (CIMPAL) in European seas

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This study represents the first pan-European assessment of the cumulative negative impacts on marine biodiversity caused by alien species invading European seas. Envisaging policy support in the combat of alien species, this assessment focuses on the identification of the most vulnerable marine regions and/or subregions, sites and habitats, while highlighting the most critical species in terms of spread and magnitude of impact, as well as their main pathways of introduction.

The results presented in this assessment are of particular relevance within several international environmental policies. In line with the targets of the Convention on Biological Diversity (CBD; UN, 2014), the recent European regulation on Invasive Alien Species (IAS; EC, 2014), along with the European Marine Strategy Framework Directive (MSFD; EC, 2008) objectives aim at addressing the consequences of pressures arising from non-indigenous species (i.e. alien species), through measurements of their impacts on the natural systems. The Cumulative IMPact of ALien species (CIMPAL) index (Katsanevakis et al., 2016) applied for this assessment is useful for the prioritization of alien species as directly requested by CBD AICHI Target 9 (providing rankings of invasive aliens) and allows following temporal and spatial trends on their impacts. In addition, such trends can be easily linked to pathways of introduction.

Methodology

CIMPAL is a semi-quantitative expert judgement-based approach to rate alien species impacts, providing a unit-less cumulative impact index. The vulnerability of marine ecosystems to the additive negative impact of marine alien species was assessed with the **CIMPAL** index (Equation 1), after Katsanevakis et al. (2016). The index (I_c) was calculated for the 10x10km EEA grid.

Equation 1 $$I_c = \sum_{i=1}^{n} \sum_{j=1}^{m} A_i H_j w_{i,j}$$

where, A_i = status of alien species i, H_j = index of the extent of habitat j, $w_{i,j}$ = impact weight for alien species i and habitat j , n = number of alien species, and m = number of marine habitats. The index is calculated in its simplified binomial version, using 0 for absence and 1 for presence of habitat (H_j) and species (A_i).

Impact weights ($w_{i,j}$) of alien species in biodiversity were defined by following the **uncertainty-averse strategy**, which accounts for the magnitude of the impacts (Table E1; Figure E1) and the strength of evidence of the information on impacts (Table E2). The classification of the magnitude of the impacts is based on the Blackburn et al. (2014) proposal adapted for the marine environment by Katsanevakis et al. (2016) (Table E1). This assessment considers only negative impacts of alien species specifically affecting biodiversity at different levels (Katsanevakis et al., 2014).

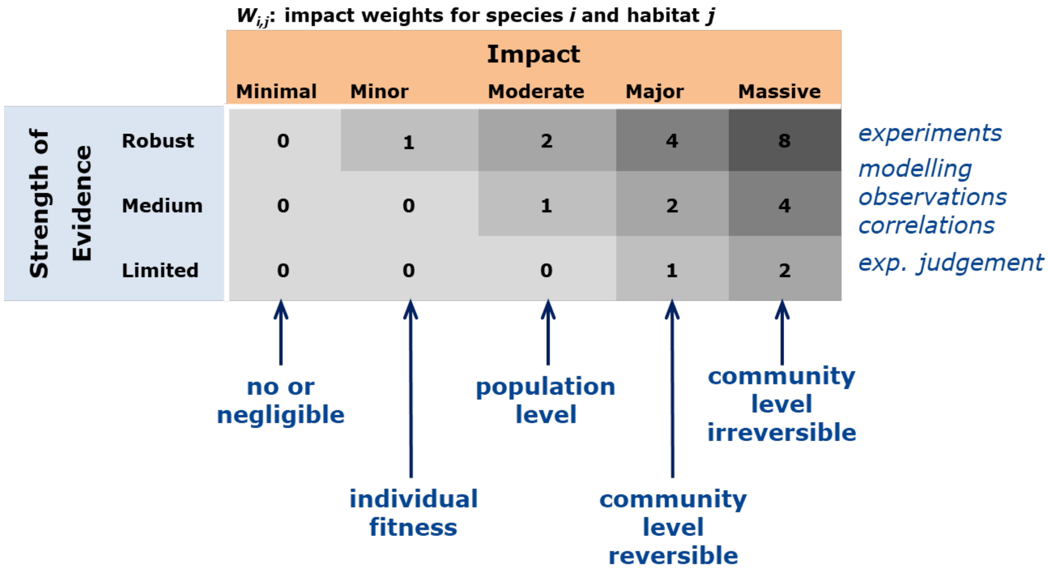
Table E1 Categories for characterizing the magnitude of the impact and respective score, adapted from Blackburn et al. 2014 and Katsanevakis et al. 2016

Impact categories: score and definition	
Minimal (0)	No effect on fitness of native species; negligible impact on native species due to competition or predation or parasitism or toxicity or bio-fouling or grazing/herbivory; negligible impact on ecosystem processes and ecosystem functioning; negligible impact on keystone species or species of high conservation value; no chemical, physical or structural impact on the ecosystem (not an ecosystem engineer).
Minor (1)	Reduction in individual fitness due to competition or predation or parasitism or toxicity or bio-fouling or herbivory, but no substantial population declines; minor impact on ecosystem processes and ecosystem functioning with no related population declines; negligible impact on keystone species or species of high conservation value; or causes changes in chemical, physical or structural habitat characteristics without decline of native populations.
Moderate (2)	Declines in population densities because of competition or predation or parasitism or toxicity or bio-fouling or herbivory, but no changes in community composition; or displacement of no more than one species of similar niche; or impact on ecosystem processes and ecosystem functioning resulting to population declines but no substantial change in species composition; or reduction in individual fitness of at least one keystone species or species of high conservation value, but no substantial population declines; or ecological engineering, resulting to population declines but no substantial change in community composition.
Major (4)	Changes in community composition and local or population extinction of at least one native species, because of competition or predation or parasitism or toxicity or bio-fouling or herbivory; impact on ecosystem processes and ecosystem functioning resulting to change in species composition; or population decline of at least one keystone species or species of high conservation value; or ecological engineering, resulting to change in community composition. Induced changes are reversible in the short term (< 1 decade) with proper management measures or if the alien species population declines naturally.
Massive (8)	The same as in 'major' but changes are irreversible in the short term (< 1 decade) or currently there is no known effective management action for the control of the invasive alien species and a natural decline of its population seems highly unlikely.

Table E2 Strength of evidence of the impact information adapted from Katsanevakis et al. 2016

Strength of Evidence categories	
High	Impact is documented based on **Manipulative Experiments** (field or laboratory experiments that include treatments/control and random selection of experimental units) or **Natural Experiments** (one of the elements of manipulative experiments is missing and the experimental units are selected by nature, i.e. not randomly)
Medium	Impact is documented based on **Modelling** (i.e. as derived from ecosystem models), **Direct Observations** (an observation or direct measurement of the impact about which there is no doubt, e.g. large-scale mortality events because of harmful algal blooms), or **non-experimental-based Correlations** (inference based on an observed correlation between the species' presence/abundance and the impact, but not based on an experimental design for data collection)
Low	Impact is based on **Expert Judgement**, usually on the basis of empirical knowledge or the species' traits or the documented impact of similar species

Figure E1: Impact weights defined on the basis of the magnitude of impact and the related strength of evidence following an uncertainty-averse strategy (adapted from Katsanevakis et al. 2016)



Criteria for alien species selection

The list of alien species considered for the current assessment includes 81 species observed within the geographical area of interest (Table E3), and which have been selected on the basis of the following criteria:

1. All alien species considered to have an impact on biodiversity of coastal and marine ecosystems in European seas have been included. The list of alien species was compiled by merging and reviewing:
   a) the list of the most impacting marine species in Europe, as of the updated inventory of 87 marine species in Europe, which have a documented high impact on ecosystem services or biodiversity (Katsanevakis et al., 2014);
   b) The list of the most invasive species in South East Europe (Karachle et al., 2017) which added newly introduced invasive species in European seas such as the brown shrimp *Penaeus aztecus* (Ives, 1891), the needlespined urchin *Diadema setosum* (Leske, 1778); the devil firefish or common lionfish *Pterois miles* (Bennett, 1828), or the *Streblospio gynobranchiata* (Rice and Levin, 1998);
   c) the list of the most impacting species archived at EASIN (EASIN v.7- 08.06.2018), i.e. AL species that are recognized to have a high impact (i.e. present in the'high-impact'or 'worst invasive'species lists of DAISIE, GISD, NOBANIS, CABI, MedPAN and SEBI-2010);
   d) new invasive species from literature, e.g. *Caulerpa taxifolia var. distichophylla* (Aplikioti et al., 2016; Musco et al., 2014);
   e) and finally, nomenclature of the species was revised, and additional species entered the list, namely *Penaeus japonicus* (Spence Bate, 1888), previously included in Katsanevakis *et al*. 2016 as *Marsupenaeus japonicus*; and *Penaeus pulchricaudatus* (Stebbing, 1914).
2. Cryptogenic (CR) species have been excluded from this assessment. Such is the case for the following 15 species: *Alexandrium minutum, Amphibalanus improvisus*, *Cordylophora caspia*, *Coscinodiscus wailesii, Gymnodinium catenatum*, *Hydroides dianthus*, *Oculina patagonica*, *Palaeomon elegans, Phaeocystis pouchetii,* Platorchestia platensis, Spartina alterniflora, *Spartina townsendii var. anglica*, *Teredo navalis*, *Bugula neritina*, *Victorella pavida*.
3. Native species in one European regional sea introduced to another regional sea are considered alien species only in the invaded area.
4. Alien brackish species have been kept and also included in the current assessment.

Table E3 Alien species considered in the current assessment (n = 81 species)

Kingdom	Phylum	Taxonomic group	Scientific name
Animalia	Annelida	Annelida	*Ficopomatus enigmaticus**
			*Hydroides elegans**
			Hydroides ezoensis
			Marenzelleria spp. (incl., M. neglecta, M.*
			Streblospio gynobranchiata
	Arthropoda	Crustacea	*Acartia tonsa**
			*Austrominius modestus**
			*Callinectes sapidus**
			*Caprella mutica**
			*Cercopagis (Cercopagis) pengoi**
			Chionoecetes opilio
			*Eriocheir sinensis**
			*Gammarus tigrinus**
			*Hemigrapsus sanguineus**
			Homarus americanus
			*Oithona davisae**
			*Palaemon macrodactylus**
			Paralithodes camtschaticus
			Penaeus aztecus
			*Penaeus japonicus**
			*Penaeus pulchricaudatus**
			*Portunus segnis**
			*Rhithropanopeus harrisii**
		Insecta	*Telmatogeton japonicus**
	Bryozoa		*Tricellaria inopinata**
	Chordata	Actinopterygii	*Fistularia commersonii**
			*Lagocephalus sceleratus**
			*Liza haematocheila**
			*Neogobius melanostomus**
			Plotosus lineatus
			*Pterois miles**
			Saurida lessepsianus
			Siganus luridus
			*Siganus rivulatus**
		Ascidiacea	*Botrylloides violaceus*
			*Microcosmus squamiger**
			*Styela clava**
	Cnidaria		*Cassiopea andromeda**
			*Rhopilema nomadica**
	Ctenophora		*Beroe ovata**
			*Mnemiopsis leidyi**
	Echinoderma		*Diadema setosum**
	Mollusca		*Anadara kagoshimensis*
			*Anadara transversa**
			Arcuatula senhousia
			*Brachidontes pharaonis**
			*Chama pacifica**
			*Conomurex persicus**
			*Crepidula fornicata**
			*Ensis directus**
			*Magallana gigas**
			*Mercenaria mercenaria**
			*Mya arenaria**
			*Petricolaria pholadiformis**
			*Pinctada imbricata radiata**
			*Potamopyrgus antipodarum**
			*Rapana venosa**
			*Ruditapes philippinarum**
			*Spondylus spinosus**
			*Urosalpinx cinerea**

Kingdom	Phylum	Taxonomic group	Scientific name
Chromista	Myzozoa		*Alexandrium monilatum*
			*Karenia mikimotoi**
	Ochrophyta		*Fibrocapsa japonica*
			Pseudochattonella verruculosa
			*Sargassum muticum**
			*Stypopodium schimperi**
			*Undaria pinnatifida**
Plantae	Chlorophyta		*Caulerpa cylindracea**
			*Caulerpa taxifolia**
			Caulerpa taxifolia var. distichophylla
			*Codium fragile subsp. fragile**
	Rhodophyta		*Acrothamnion preissii**
			*Asparagopsis armata**
			*Asparagopsis taxiformis**
			*Bonnemaisonia hamifera**
			*Gracilaria vermiculophylla**
			Grateloupia turuturu
			*Lophocladia lallemandii**
			Polysiphonia morrowii
			*Womersleyella setacea**
	Tracheophyta		*Halophila stipulacea**

Alien species' occurrences

The data covers from historical records to recent reported occurrences, namely until 2018 for the Mediterranean and 2016-17 for other regional seas (as for the rest of the EU seas the most recently published data was not included). Georeferenced data for the selected alien species were provided by (1) HCMR and the EEA offline database for the Mediterranean (last update from July 2018); (2) EASIN – JRC geodatabase (data up to the summer of 2017); (3) EurOBIS and MEDOBIS data (data up to December 2016) kindly provided by OBIS – European node of the Ocean Biogeographic Information System (EurOBIS, 2017). Available online at www.eurobis.org; the EurOBIS data policy is explained at http://www.eurobis.org/citation.

The 81 alien species species included in this assessment registered a total of 61150 validated georeferenced occurrences (Lat/Long) in our database, within the spatial context of the current assessment.

Ecosystems assessed

This assessment focuses on the negative cumulative impacts of alien species on coastal and marine ecosystems, for which main habitat types were considered. In addition to coastal and marine waters, also coastal littoral zones, estuaries and coastal lagoons were included in the assessment, whenever spatial data was available. Excluded were the coastal areas of the Ukraine and Georgia (in the Black Sea), and of the Russian Federation (in the Baltic and Black Sea). A simplified reduced list of 16 habitat categories was the basis for assigning the negative impacts of alien species in biodiversity (Table E4). A correspondence of these habitats was then established with habitat categories in the different sources of spatial information assembled to map the distribution of habitats.

Table E4 Reduced list of 16 habitats used in this assessment for assigning species negative impacts

Reduced list of habitats	Source	Equivalence to habitats in source
Estuaries & coastal lagoons infralittoral	Derived from Copernicus Water & Wetness 2015	Coastal water surfaces: lagoons, estuaries (WWPI ≥ 95 %)
Estuaries & coastal lagoons littoral	Derived from Copernicus Water & Wetness 2015	Intertidal areas (WWPI ≥ 60 %)
Coastal wetlands (incl. salt marshes)	Derived from Copernicus Water & Wetness 2015	Coastal wetlands (incl. salt marshes) (WWPI ≥ 20%)
Coastal intertidal softbottoms	This work	Coastal littoral zones (beaches and/or rocky shores)
Coastal intertidal rocky shores	This work	Coastal littoral zones (beaches and/or rocky shores)
***Posidonia* beds**	Emodnet euseamap2016	A5.535 and dependencies
Seagrass-seaweed beds	Emodnet euseamap2016; and derived from Copernicus Water & Wetness 2015	A5.531: Cymodocea beds; Coastal water surfaces: lagoons, estuaries (WWPI ≥ 95 %); Intertidal areas (WWPI ≥ 60 %)
Coralligenous	Emodnet euseamap2016	A4.26 or A4.32: Mediterranean coralligenous communities moderately exposed to or sheltered from hydrodynamic action
Shallow sediment (< 60)	Emodnet euseamap2016	See correspondence in **Sup. Mat. 3**
Shallow rock (< 60)	Emodnet euseamap2016	See correspondence in **Sup. Mat. 3**
Circalittoral sediment (60–200)	Emodnet euseamap2016	See correspondence in **Sup. Mat. 3**
Circalittoral rock (60–200)	Emodnet euseamap2016	See correspondence in **Sup. Mat. 3**
Bathyal-abyssal sediment (> 200)	Emodnet euseamap2016	See correspondence in **Sup. Mat. 3**
Bathyal-abyssal rock (> 200)	Emodnet euseamap2016	See correspondence in **Sup. Mat. 3**
Pelagic (< 200)	Emodnet bathymetry portal	derived from bathymetric data: 0 to 200 m depth
Mesopelagic (200–1,000)	Emodnet bathymetry portal	derived from bathymetric data: 200 to 1,000 m depth

Habitat spatial data

A 10 x 10 km standard grid covering EU regional seas was used, based on the EEA reference grid (Lambert equal-area projection). It included EEA member countries but also all marine waters in non-EU countries in the Mediterranean and in some non-EU countries in the Black Sea. The total number of unique cells in the grid was 102,364. Macaronesia, Iceland Sea, Norwegian Sea and part of the Barrents Sea, although covered by the grid, were not considered for the assessment. Coastal zones are also covered by this grid, although cells cropped along the coast- line often account for a smaller area. Hence, the number of cells considered for the current assessment represents an approximate total area of 5,151,190 km^2.

For characterizing habitats' distribution and mapping, different spatial datasets were assembled. Most of the spatial information for the habitat categories considered in this study (Table E4) is based on the **EMODnet broad-scale seabed habitat map for Europe 2016** (AKA **EUSeaMap 2016**, as of 30th September 2016). Estuarine and coastal lagoons' habitats, not covered by the EUSEAMAP2016 data, have been derived from the **COPERNICUS Water and Wetness 2105** product (as of 8th April 2018), which provides information on the occurrence of water and wet surfaces over the period from 2009 to 2015 (100 m resolution). Coastal littoral habitats, also not included in the EUSEAMAP2016 layer, have been assumed to occur, by default, in the coastal area ranging from the EUSEAMAP layer limits until the coastline delimitation (**EEA, 2017b coastline for analysis).** Finally, the two pelagic habitat layers were derived from the **EMODnet bathymetric data,** where shallower depths (0 to 200 m) were defined as pelagic and deeper waters over the seafloor as mesopelagic (200 m to 1,000 m).

References of Annex E.

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