Human activities and resultant pressures on key European marine habitats: an analysis of mapped resources

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Abstract

Human activities exert a wide range of pressures on species, habitats, and ecosystems. In many cases human activities result to the degradation of marine ecosystems and our ability to restore them from past damage and limit future impacts is hindered by a lack of knowledge of the extent, duration and severity of the pressures on marine ecosystems. Central to the development of effective policy and conservation interventions is an understanding of where and when such activities and pressures occur. This study provides a comprehensive assessment of mapped human activities and pressures acting on the marine environment in European seas through an exhaustive review of published records, web resources, and grey literature compiled by the EU H2020 project "Marine Ecosystem Restoration in Changing European Seas" (MERCES). The results highlighted a number of limitations and gaps, including: (a) limited geographic coverage both at the regional and sub-regional levels; (b) insufficient spatial resolution and accuracy in recorded data for the planning of conservation and restoration actions; (c) the lack of access to the background data and metadata upon which maps are based, thus limiting the potential for synthesis of multiple data sources. Based on the findings, several recommendations for future marine research initiatives arise, most importantly the need for coordinated, geographically extended baseline assessments of activities and pressures, complying with high-level standardisation regarding methodological approaches and the treatment of produced data.

Keywords: mapping; ecosystem restoration; marine spatial planning; conservation

1. Introduction

Human activities such as fisheries, transport, tourism, mining and energy generation exert multiple pressures on the marine environment which contribute to ongoing habitat degradation and loss (e.g. Airoldi & Beck, 2007; Korpinen et al. 2013). In turn, such changes reduce the capacity of marine ecosystems to deliver valuable ecosystem services and increase their sensitivity to future impacts such as those associated with climate change (Ramirez-Llodra et al. 2011). In addition, they hamper progress towards global, regional and national efforts to conserve, restore and sustainably use the marine environment, such as UN Sustainable Development Goals, the EU Marine Strategy Framework Directive (MSFD) and Marine Biodiversity Strategy, Maritime Spatial Planning Directive (MSPD) and the EU Blue Growth agenda (Cavallo et al. 2017).

The degree to which human activities impact the marine environment is a function of: (i) the pressures associated with an activity (e.g. the activity of fishing may exert the pressure of abrasion on the seabed), (ii) the sensitivity of a specific habitat over the above pressures, and (iii) the intensity and duration of the pressures and the spatial and temporal footprint over which they occur. Spatial maps of activities and their associated pressures are therefore essential to monitor, mitigate and reduce their impact, for example through marine spatial planning (Ansong et al. 2017). Specifically, spatial information can be used to highlight where action is needed to remove or reduce stressors (e.g. Stewart et al. 2010); forms the basis of species and habitat vulnerability assessments (Lauria et al. 2017) and aids the design and spatial arrangement of marine protected areas (Gonzalez-Mirelis et al. 2014).

Whilst global assessments of human impacts, such as those undertaken by Halpern et al. (2008), outline broad scale patterns of human impact upon marine ecosystems, the degree to which they accurately represent the magnitude and spatial patterns of human activities and pressures at regional, national and local levels depends upon the representativeness of the underlying data. Within Europe, significant effort has been expended documenting, categorising and mapping human activities and their associated impacts (Coll et al. 2011; Micheli et al. 2013; Korpinen and Andersen 2016), for example, through the MSFD (EC 2008; Loizidou et al. 2017) and outputs from multiple EU projects and academic research. Despite significant progress, there remain data gaps and a poor understanding of the temporal and spatial elements of the activities and pressures (Costello et al. 2010; Korpinen et al. 2012; Korpinen & Andersen 2016). Nevertheless, whilst such limitations and biases are known to exist, the extent of data gaps and the degree to which they are spatially or temporally distributed remains unclear. With this in mind, the aim of this paper is to produce for the first time an inventory of available spatial information relating to anthropogenic activities and pressures within European regional seas as defined by the MSFD, in order to identify limitations and gaps in knowledge and help focus future research efforts and data collection where it is most needed.

2. Methodology

Activities and pressures of interest

Activities and pressures were defined as follows: *Activity* - a human action or endeavour that has the potential to create pressures on the marine environment, e.g. aquaculture or tourism (Scharin et al. 2016); *Pressure* - the mechanism through which an activity has an actual (or potential) impact on the ecosystem (Robinson et al. 2008). Following Elliot (2011) pressures are divided into two types: *endogenous*, i.e. those emanating from within the system and are directly manageable (e.g. abrasion on the seabed caused by trawling activities) and *exogenous*, i.e. those emanating from outside the system and cannot be directly managed (e.g. a change in seabed morphology from tectonic events).

In total thirteen activities, as well as twenty-six endogenous and seven exogenous pressures are considered (Table 1), based on those defined in the MSFD and Smith et al. (2016); definitions and examples for those are provided in Table S1-Supplemetary Material.

Table 1. List of activities and pressures (endogenous and exogenous) acting on marine habitats that were considered in the present study; definitions in Smith et al. (2016).

Activities	Pressures (endogenous)	Pressures (exogenous)
Agriculture	Abrasion	Change in wave exposure
Carbon sequestration	Aesthetic pollution	Emergence regime change
Coastal and marine infrastructure	Barrier to species movement	Geomorphological changes
Defense and security	Change in wave exposure (local)	pH changes
Extraction of living resources	Changes in siltation and light regime	Salinity regime change
Extraction of non-living resources	Collision	Thermal regime change
Land-based industry	Electromagnetic changes	Water flow rate changes
Non-renewable energy generation	Emergence regime change (local)	
Production of living resources	Input of organic matter	
Renewable energy generation	Introduction of microbial pathogens	
Research and conservation	Introduction of non-synthetic compounds	
Tourism/recreation	Introduction of other substances	
Transport	Introduction of radionuclides	
	Introduction of synthetic compounds	
	Introduction/translocations of non-indigenous species	
	Litter	
	Nitrogen and phosphorus enrichment	
	Noise	
	pH changes (local)	
	Salinity regime change	
	Selective extraction of non-living resources	
	Selective extraction of species	
	Smothering	
	Substratum loss	
	Thermal regime change	
	Water flow rate changes (local)	

Sourcing and inventorying information

A systematic literature search was conducted to identify spatial information relating to activities and pressures within European regional seas (see below for a full list and relevant definitions). A standard web search was performed, supplemented with queries in two research databases (ISI Web of Science and Scopus) in order to ensure full coverage of the published evidence. Searches were targeted using keywords and keyword combinations relating to mapping of the activities and pressures taken into account within the area of interest (a full list of keywords used is provided in Table S2-Supplemetary Material). The first 100 results of each search, ranked by relevance, were examined for extraction of relevant information. Specific web resources of international organizations, commissions and agencies active on marine conservation (EEA, IUCN, UNEP-MAP-RAC/SPA, HELCOM, OSPAR, FAO, OCEANA, MarLIN) and European projects registered in the European Marine Spatial Planning platform (e.g. MEDTRENDS, CoCoNet, MESMA, PERSEUS, ADRIPLAN, THAL-CHOR, BALANCE) were also queried for all available material (including downloadable reports). The results of the above search were complemented by input from the MERCES consortium experts who were asked to provide potentially missing data entries based on their thematic expertise and regional knowledge. Searches extend to all records available as of the end of 2016.

An inventory was assembled, cataloguing the following information for each resource identified:

1. The specific activities and pressures considered (see above for categorization).

2. The region and subregion of spatial coverage; this includes:

   - The MSFD region of the study: Baltic Sea; North-East Atlantic; Mediterranean Sea; Black Sea or Other (such as Norwegian waters, or seafloor banks in the international waters of North-East Atlantic).
   - The sub-region: North-East Atlantic (Greater North Sea, including the Kattegat, and the English Channel; Celtic Seas; Bay of Biscay and the Iberian Coast), Macaronesian biogeographic region (Azores; Madeira and Canary Islands), the Mediterranean Sea (Western Mediterranean; Central Mediterranean; Adriatic; Ionian and the Aegean-Levantine Sea).

3. The particular habitat type examined (see below for categorization), if applying; lacking specific indication regarding habitat, the source was characterized as ‘broad-scale’.

4. The type of information provided: map image; map viewer (interactive image on-line); GIS georeferenced file.

5. The source of information: on-line resource/website; scientific paper; report; conference proceedings; expert/unpublished.

Habitats over which activities and pressures take place

Fifteen habitats or keystone species of high ecological importance, conservation interest and/or those which are known to be particularly sensitive to -or threatened by- human activities (e.g. EU Habitat Directive 92/43/EEC, OSPAR List of Threatened and/or Declining Species and Habitats, OSPAR 2008, UNEP/MAP-SPA/RAC 2018 Annex II List of Endangered or threatened species, Ramirez-Llodra et al. 2011; Smith et al. 2014) were identified for the cataloguing purposes in the present study, as outlined below:

Sublittoral soft-bottom:
- Seagrass beds (*Posidonia*, *Zostera*, other seagrasses)
- Other

Sublittoral hard-bottom:
- Maërl beds
- Coralligenous formations
- Gorgonian forests and sponge beds
- Macroalgal forests/beds (*Cystoseira* or other canopy-forming algae)
- Other

Deep-sea (>200 m depth):
- Coral gardens
- Sponge aggregations
- Mixed coral/sponge aggregations
- Seamounts
- Hydrothermal vents
- Carbonate mounds
- Canyons
- Other

Broad-scale:
- No specific habitat identified

3. Results

In total, 264 records with relevant information were collected and included to the analysis, of which 194 included maps of activities, 147 included maps of endogenous pressures, and 43 included maps of exogenous pressures. A considerable number (101) reported both activities and endogenous pressures.

Information by source and format

Nearly half of the sourced records (49%) originated from peer-reviewed journals (Figure 1A). However, a substantial amount of information was derived from grey literature, at a 27% from project reports; 19% from web resources; 4% from conference proceedings and 1% from unpublished information (unpublished data/expert opinion). The majority of records contained just map images (86%), with interactive map viewers limited to 9%, and downloadable georeferenced files (e.g. shapefiles) to 5% (Figure 1B).

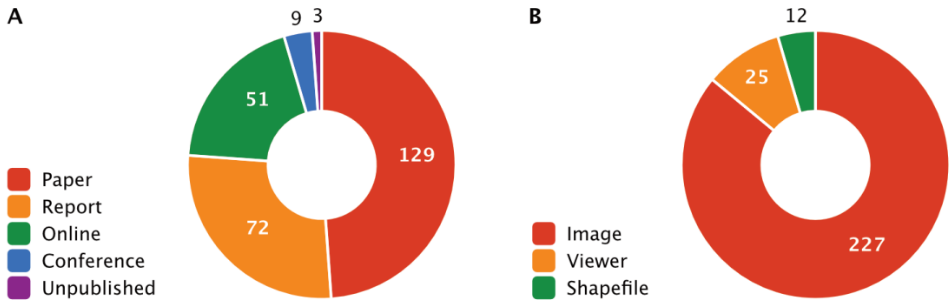

Figure 1. Sources (A) and format (B) of records containing spatial information on anthropogenic activities and/or pressures.

Information by geographic area

The majority of records were from the Mediterranean Sea (39%) and the North-East Atlantic (27%); with the Baltic and Black Seas represented to a much lesser extent (16% and 14%, respectively) (Figure 2). At the sub-regional level, the North-East Atlantic was represented mostly by records from the Greater North Sea and the Celtic Seas (54% and 31%, respectively); a small portion of records (6%) included maps at the regional scale. Regarding the Mediterranean Sea, all four MSFD sub-regions were represented, and a significant portion of records (27%) included maps at a pan-Mediterranean scale. "Other" regions (i.e. records with a global coverage, those covering the entire European continent, sub-regions outside the EU, or regions which are not MSFD-relevant) represented 16% of the records.

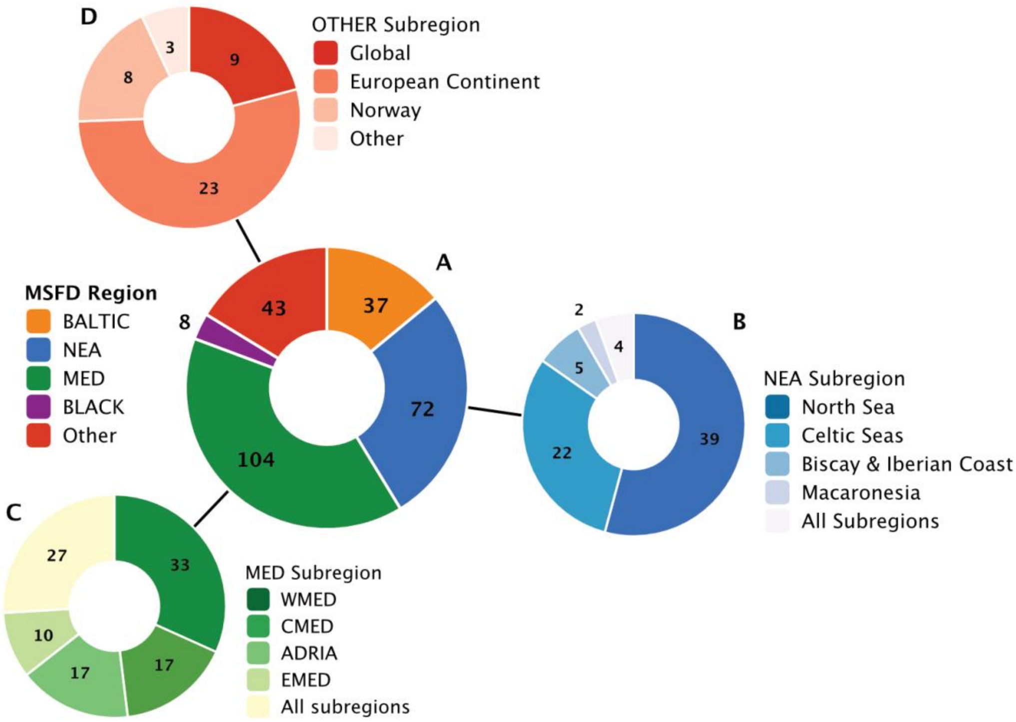

Figure 2. Number of records for European regions and sub-regions. A) Regional seas (BALTIC: Baltic Sea; BLACK: Black Sea; MED: Mediterranean Sea; NEA: North-East Atlantic; Other: Other regional sea), B) North-East Atlantic sub-region, C) Mediterranean Sea sub-regions (WMED: Western Mediterranean; CMED: Central Mediterranean; ADRIA: Adriatic; EMED: Eastern Mediterranean), and D) Non-MSFD regions.

Information by habitat

Seventy-five percent of the records were characterised as 'broad scale', spanning multiple habitats and depth zones without any further details provided (Figure 3). Of the remaining 25%, the majority covered general shallow hard and soft habitats, such as coralligenous reefs (including gorgonian forests), euphotic reefs with macroalgal forests, and seagrass beds. Within the deep-sea category (accounting for 6% of the total records), activities and pressures were most frequently mapped over canyons and coral beds.

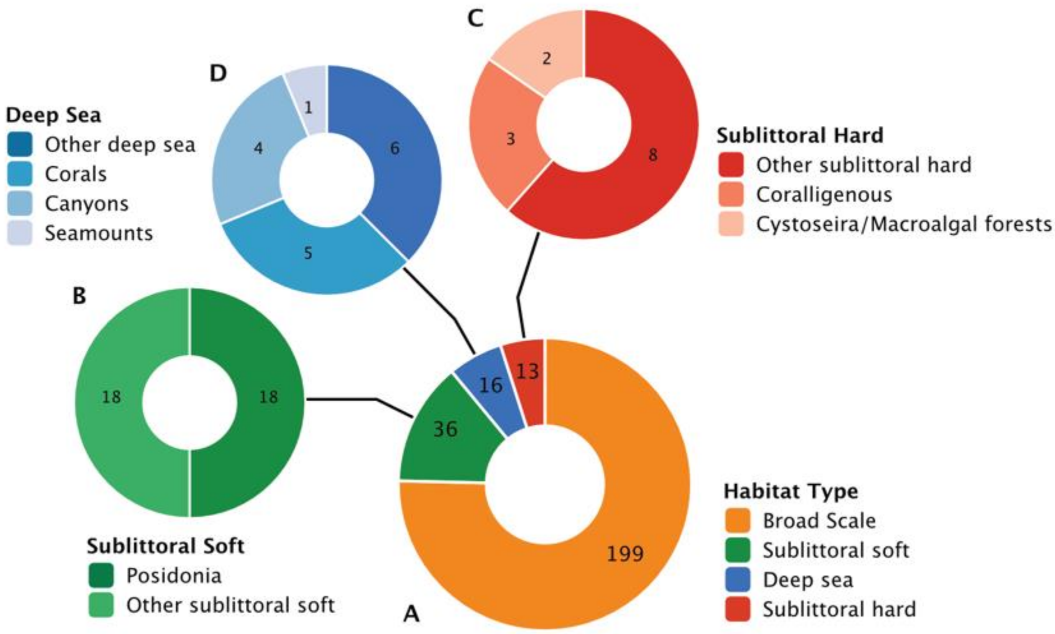

Figure 3. The number of records per habitat type (A), broken down by sublittoral soft (B), sublittoral hard (C) and (D) deep-sea habitats.

The paucity of information relating to specific habitat types was consistent across all geographic sub-regions, although the relative percentages differed (Figure 4). Within the Mediterranean Sea, 45% of the records referred to specific habitats, with smaller percentages seen in the remaining regions. In the Baltic and Black Seas, only "sublittoral soft bottom" habitats were identified.

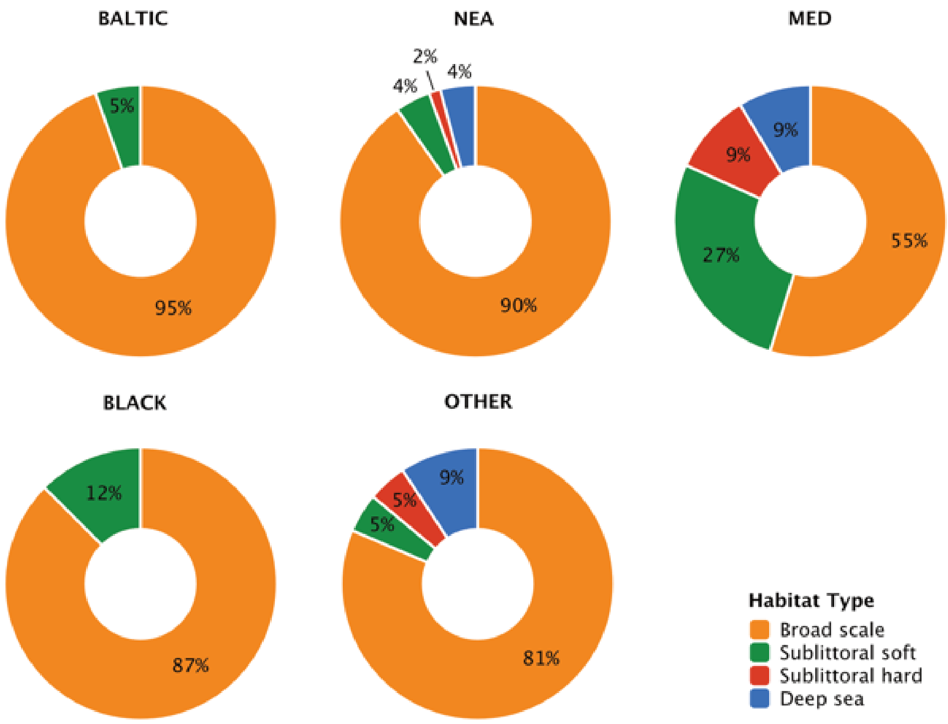

Figure 4. The number of records of habitat types by geographic region (for abbreviations see Figure 2).

Information by activity

"Extraction of living resources" was found to be the most frequently mapped activity represented in 39% of the records (Figure 5). "Coastal and marine structure and Infrastructure", "Transport" and "Production of living resources" were the next most frequent, mapped in 29%, 27%, and 26% of the records, respectively. "Research and conservation" was relatively poorly represented (only 8%), whilst "Carbon sequestration" (i.e. offshore CO_2 storage requiring seabed intervention) and "Agriculture" had the lowest number of records.

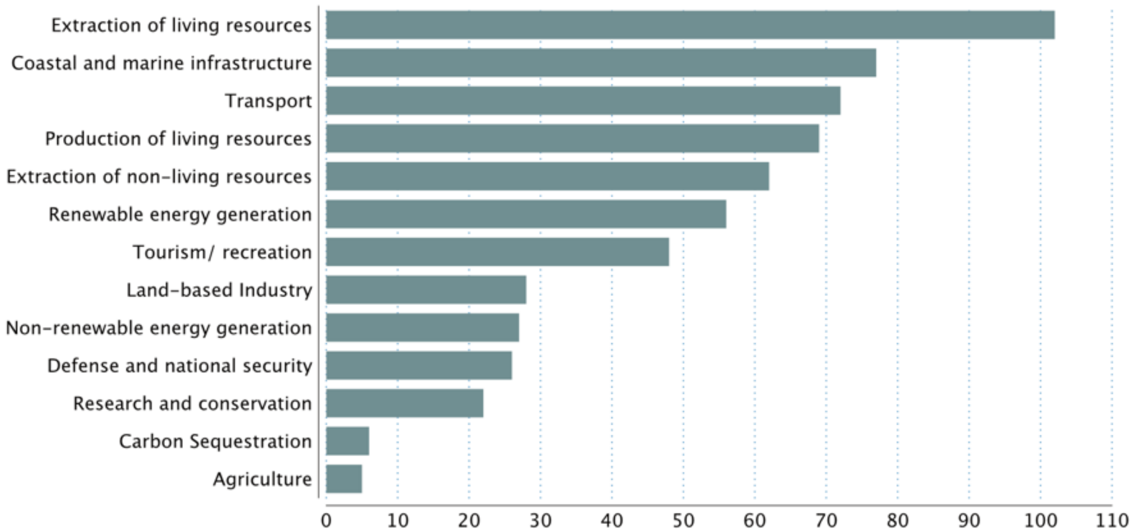

Figure 5. Mapped activities ranked by number of records.

Records of all activities occurred in the North-East Atlantic, Mediterranean and Baltic Seas (Figure 6) but their relative importance varied. An abundance of mapped sources for "Production of living resources" (i.e. aquaculture) and "Tourism/recreation" were retrieved for the Mediterranean Sea, reflecting the importance of these sectors in the specific region. Correspondingly, mapping of "Extraction of non-living resources" and "Renewable energy generation" was pronounced in the North-East Atlantic, similar to "Transport" in the Baltic Sea and Norway.

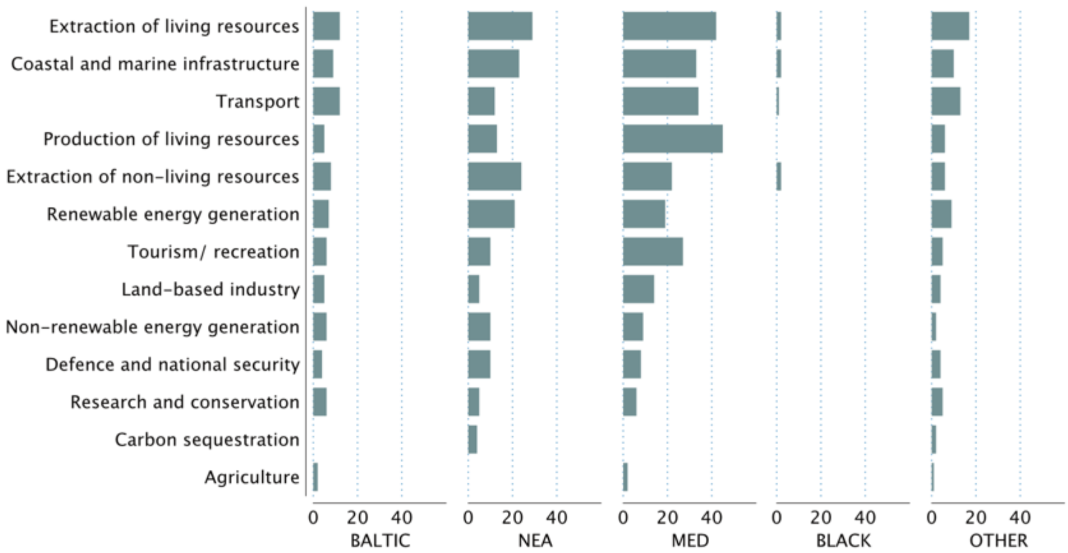

Figure 6. Mapped activities by geographic region (for abbreviations see Figure 2).

Information by endogenous pressure

Overall, pressures relating to chemical substances and chemical influxes accounted for the highest number of records, with “Nitrogen and phosphorous enrichment”, “Introduction of other substances” and “Input of organic matter” present in 17%, 15%, and 13% of the records, respectively (Figure 7). Of the other endogenous pressures that collectively accounted for more than 20% of the records, “Abrasion”, “Introduction of non-indigenous species” and input of “Litter” were the most frequently noted. There were only a few records relating to local “Thermal regime changes”, input of “Underwater noise”, “Selective extraction of non-living resources”, and “Barriers to species movement”.

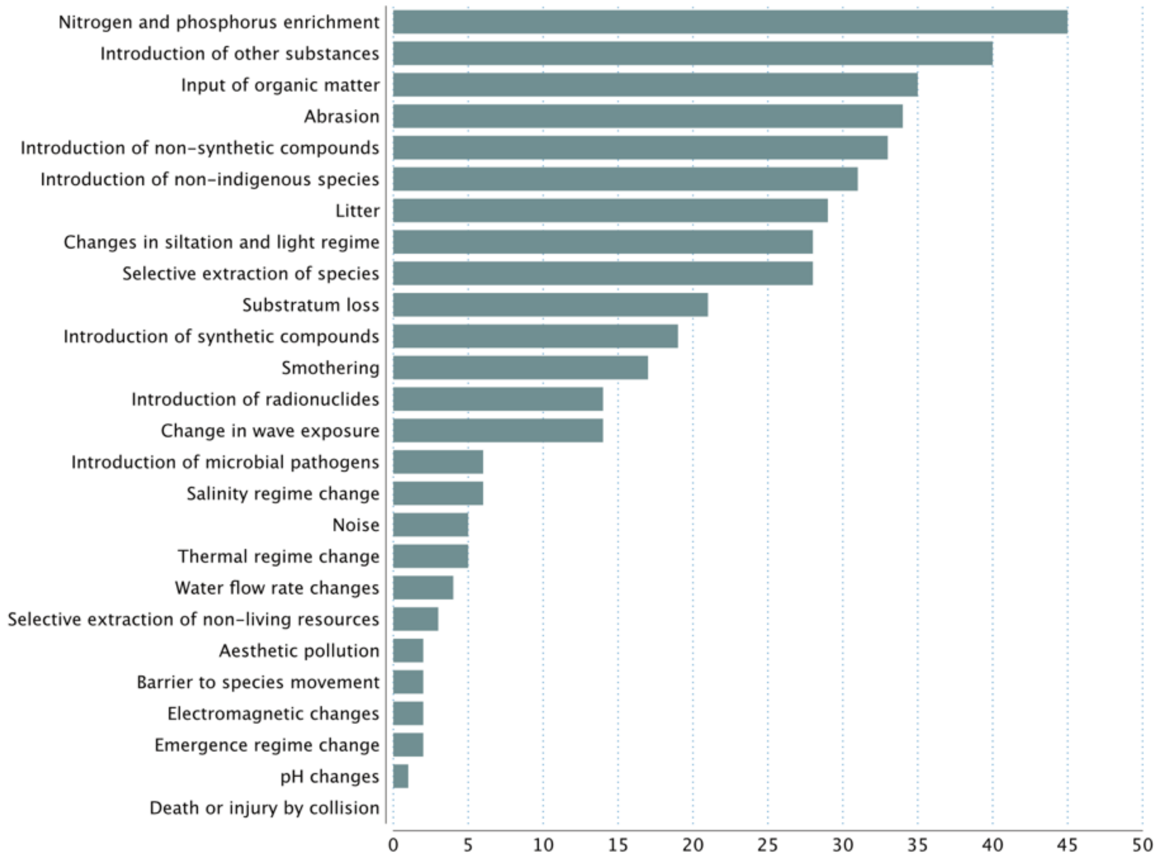

Figure 7. Mapped endogenous pressures ranked by number of records.

The majority of important endogenous pressures are recorded in all the regions examined, with relative importance varying regionally (Figure 8). "Introduction of non-indigenous species" and "Litter" are frequently mapped in the Mediterranean Sea, while local "Change in wave exposure" appears only mapped in the specific region. Hydrological change and other physical disturbance-related pressures (e.g. "Smothering", "Abrasion") are most often mapped in the North-East Atlantic. Introduction of substances such as non-synthetic compounds and radionuclides is relatively more frequently mapped in the Baltic Sea. Notably, no collective litter maps for the latter region have been available by HELCOM to day. The Black Sea appears relatively deprived regarding mapped sources of pressures acting on its marine environment.

Figure 8. Mapped endogenous pressures by geographic region (for abbreviations see Figure 2).

Information by exogenous pressure

Overall, “Thermal” and “Emergence” regime changes (wide-area, e.g. climate-induced change) were the most frequent exogenous pressures identified in the records (13% and 9%, respectively), followed by changes in pH (Figure 9). In general, there is limited information and regional maps of exogenous pressures with slightly more for the Mediterranean and other regions (Figure 10).

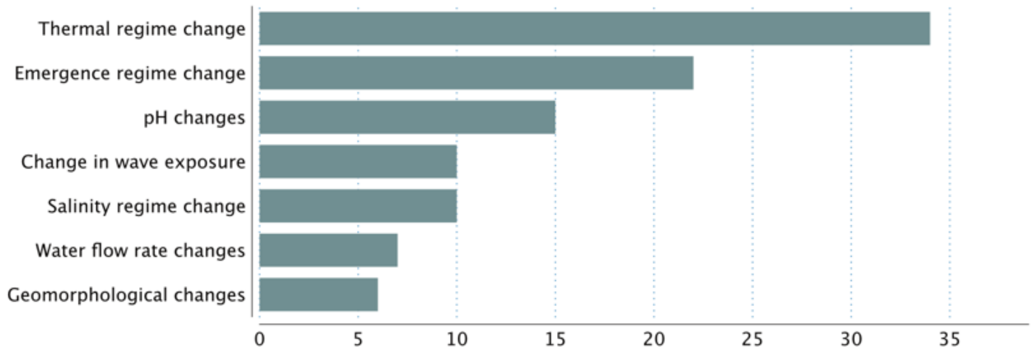

Figure 9. Mapped exogenous pressures ranked by number of records

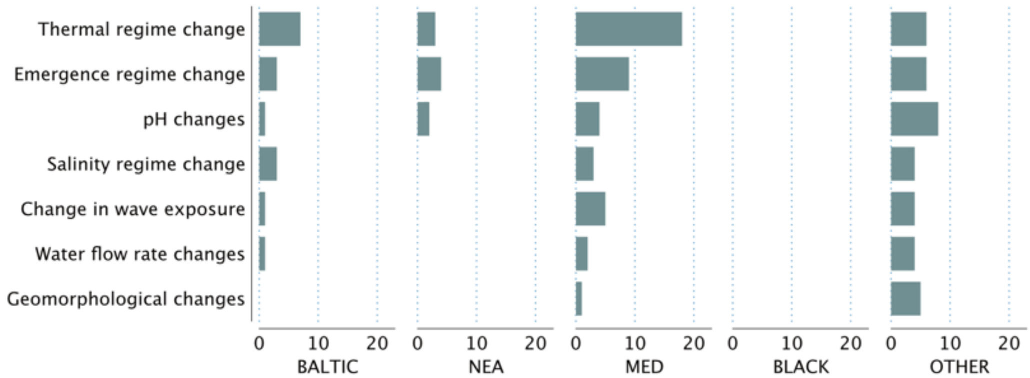

Figure 10. Mapped exogenous pressures by geographic region (for abbreviations see Figure 2).

4. Discussion

European seas and adjacent coastal areas have a long history of intense development and are of significant economic importance to the region (Randone et al. 2017), having been valued at 500 to 1000 billion Euros for the economic assets within 500 metres of coastline (EEA 2007). Consequently, they are also among the most severely degraded marine systems worldwide (e.g. Coll et al. 2011; Benn et al. 2010; Costello et al. 2010). Recently, an increased political and societal awareness of the condition of the marine environment and a recognition of its importance to society have resulted to concerted efforts to transition to a more sustainable and ecologically conscious future (Boyes et al. 2014; 2016). This has resulted in substantial time and funds being spent on classifying, documenting and mapping human activities and pressures in European waters (e.g. through the Water Framework Directive along with the MSFD and MSPD, work by the European Environmental Agency, EMODnet, OSPAR and HELCOM and an array of research efforts such as the VECTORS, DEVOTES, PERSEUS, BENTHIS, ADRIPLAN and Med-IAMER projects). However, due to differences in capacity between regions and institutions, and biases in political and scientific focus, the current level of knowledge is fragmented and incomplete.

The comprehensive review and analysis undertaken here highlights limitations and gaps in our current level of understanding, which –if filled– would provide crucial information to support conservation, policy, and economic sectors.

Coverage of human activities and pressures

The extraction of living resources is the most frequently documented activity and is generally expressed as the area of fishing activity, the amount of catch, the size of the fishing fleet or fishing effort. Such information, supplemented by new data from Vessel Monitoring Systems (VMS), render this activity easy to track and quantify, resulting in maps of varying spatial scale and adequate detail (e.g. see Eigaard et al. 2016; Benn et al. 2010). However, accurate catch data are not always available (Piroddi et al. 2015; 2017), while the coverage is at present incomplete due to the absence of VMS data for certain fleets (e.g. small artisanal) but also due to the confidentiality of the data. The production of living resources, which relates to aquaculture, is also relatively well-documented. This information tends to be documented and mapped at the national level and, as a result, data can be combined to provide a regional overview (e.g. Trujillo et al. 2012). Oil and gas exploitation and exploration is another commonly mapped activity (e.g. Piante & Ody 2015), with information available on the location of pipelines and landing points. Due to the fact that such operations are often planned years into the future, in addition to the existing location of activity, it is also possible to obtain potential locations which is an asset for spatial conservation planning and in balancing the competing demands for space in the ocean.

As far as pressures are concerned, many endogenous pressures are commonly represented in maps, such as the introduction of chemicals and compounds (e.g. EEA, 2015), marine litter (e.g. Pham et al., 2014) and abrasion (usually directly linked to trawling patterns and intensity, e.g. Eigaard et al. 2016). However, other pressures appear to be under-represented (e.g. underwater noise or change in wave exposure), or absent (e.g. death of large vertebrates, such as cetaceans, by collision). This may be because these pressures are not significant in particular study areas, or more likely, because they are not frequently assessed (underwater noise for example was only recently made a priority for assessment under the MSFD, and knowledge gaps hamper assessments, see Crise et al. 2015) and when they are, they are not mapped at broad scales.

Compared to endogenous pressures, the location and intensity of exogenous pressures are very poorly documented. Whilst warming trends, sea-level rise and acidification are mapped, albeit to a lesser extent, other pressures such as changes in salinity and water flow are somewhat neglected, despite the significant impact they can have on marine species and ecosystems (Harley et al. 2006; Danovaro et al. 2017) and their high ranking as drivers of environmental change among experts (Boonstra et al. 2015).

There is also variation in relation to how the activities and pressures are mapped, and the degree to which they were quantified, which is often related to the nature and type of the activity (i.e. fixed or mobile). Specifically, locations of mining or hydrocarbon extraction, fish farms, shipping routes, locations of ports are predominately mapped as geographic points indicating the presence of the activity, while other activities, such as fishing effort, density of marine traffic, intensity of tourism, are depicted as concentrations of activities over set areas.

Breakdown by region(s)

Regional cooperation is of paramount importance for a number of flagship EU directives and policies (e.g. MSFD, MSPD), as well as the sustainable management of resources (e.g. shared fish stocks – Heffernan 2014) and the attainment of conservation goals (e.g. managing non-indigenous species – Katsanevakis et al. 2015); it is therefore important that comparable attention is given to all regions and that additional research effort is directed to those areas that are data deficient.

The majority of mapped resources covers the Mediterranean Sea and North-East Atlantic, presumably due to the highly active scientific fora and advisory bodies such as CIESM and ICES and the long history of human use and exploitation –but also baseline research– in these areas. In addition to specific regions, a substantial portion of records is on the global or European scale, an expected outcome since those arise from much larger scale initiatives (e.g. Nelleman et al. 2009).

The Baltic Sea is especially well documented in terms of pressures (Korpinen et al. 2012), biodiversity (Ojaveer et al. 2010) and impacts (e.g. HELCOM 2009) and has several functional, basin-wide management programmes coordinated through the Helsinki Commission (HELCOM). The lower number of records from the Baltic Sea is not related to data deficiency, but –contrastingly– is the result of great efforts made by HELCOM in synthesizing available information and different data sources in harmonised pan-Baltic maps; this coordinating effort renders a substantial amount of data available at the pan-Baltic level and therefore has high information value.

In comparison, the Black Sea, which is 30% larger than the Baltic Sea, only has a small number of records and is certainly under-represented in terms of mapping initiatives and available data. The difference between these two regional seas is likely attributable to a reduced research effort and/or limited communication/publication of study results in the Black Sea region. Nevertheless, this is likely to change in the future as several initiatives have recently been launched in the region which will increase the state of knowledge (e.g. through IP projects such as MARSPLAN-BS, MISIS, CoCoNet and PERSEUS). Furthermore, the European Commission is also supporting research institutes and public stakeholders from all Black Sea countries to pool together existing data in order to create a single digital map of the Black Sea seabed, including its geology, habitats and marine life (based on the EMODNET example).

Breakdown by habitat(s)

The majority of reviewed maps do not indicate the presence of, or impact on, specific habitats. While this is in part due to the scope of the present analysis (i.e. to identify maps documenting activities/pressures at the regional or national level), it also highlights a clear limitation in our current knowledge. Whilst it is possible to overlay maps of activities and pressures with habitat distribution and make inferences regarding the impact, quantifiable evidence is obviously more informative; thus, refined data on the distribution and intensity of human pressures should ideally be coupled with habitat-specific calibration of thresholds in impact scores to provide a more realistic picture of the severity of cumulative impact across habitats (e.g. see Bevilacqua et al. 2018).

Contextual information

Context is essential to help translate maps of activities and pressures from indicators of possible impact to more detailed indicators of likely impact (Andersen & Stock 2013, Stelzenmüller et al. 2018) and therefore increase their utility to inform adaptive management policies and develop successful restoration projects. For example, whilst a specific activity (e.g. fishing) has the potential to cause a specific pressure (e.g. abrasion), the latter may only apply in a particular location (e.g. where a specific habitat is present) or time period (Puig et al. 2012). Furthermore, even if a pressure is present, its impact upon the marine environment will vary as a function of its timing, frequency, intensity, duration and spatial footprint (Knights et al. 2015). Cumulative pressure impact assessments try to account for some of these issues although other challenges remain, for example: (i) non-linear pressure responses and non-additive (antagonistic or synergistic) pressure effects are not well understood (Halpern & Fujita 2013) and (ii) modelled outputs from large basin-wide studies (e.g. Halpern et al. 2008; Korpinen et al. 2012; Micheli et al. 2013; Goodsir et al. 2015) have questionable ability to represent real conditions at the local scale (Guarnieri et al. 2016) although finer scale applications at the habitat level do begin to appear (Bevilacqua et al. 2018).

Contextual information generally tended to be lacking: whilst certain types of information (e.g. VMS) have highly accurate geo-positioning (10 m accuracy), their frequency of recording is low and by the time the data are processed and made available, the activity is often presented at a coarser 2000 m resolution; differences in the spatial resolution of the fishing pressure in maps result in significant differences as to where the footprint of the activity is placed, especially in areas where depth changes occur, and therefore in an assessment of the habitats affected (Eigaard et al. 2016). Yet, these limitations can be overcome in the near future via widespread use of real-time Automatic Identification System (AIS) and public release of VMS data (Kroodsma et al. 2018).

The same is true for interpolated maps based on modelled data, which are often relatively coarse in scale. Such limitations make it difficult to infer the true extent of an activity at local levels, and therefore efforts to implement effective regulatory policies are hindered. In addition, modelled “footprints” of activity often lack actual parameters on intensity, temporal variation, and duration. Furthermore, the majority of maps depict a single snapshot in time and, as such, it is difficult to infer the frequency over which certain pressures and activities operate and to project future trends.

The coastal zone is crowded and subjected to an ever-increasing demand for space (EEA 2015). A better understanding of the temporal patterns of human activities will aid the development of more efficient spatial plans and will facilitate the integration of planning where hotspots of human pressure occur and where critical habitats and species’ movements (e.g. migrations or spawning and breeding areas) are present and in need for conservation in order to reduce negative impacts (Colloca et al. 2015). In addition, the majority of data sources do not provide downloadable georeferenced files. This hampers efforts to make inferences for certain sensitive habitats or determine the actual spatial footprint of activities from which impacts can be derived; consequently, the lack of georeferenced files limits the usability of the data for further synthesis, analyses and conservation planning.

A specific attempt to produce a census of available maps of key European marine habitats has been recently completed by Bekkby et al. (2017). Furthermore, whilst it was outside the scope of this review, there is also a pressing need to combine activity and pressure maps with biological information to obtain a more nuanced understanding of the degree of impact (Eigaard et al. 2016; Rijnsdorp et al. 2016).

Summary of gaps, limitations and recommended next steps

- **Static data**: The majority of spatial information is limited to images of maps, greatly reducing their usability and applicability to other studies. These images are static in time, while activities and pressures in marine habitats (as well as the marine habitats themselves) are temporally dynamic.
- **Potential interactions between pressures:** Pressures can interact in complex ways, and cumulative and non-additive effects have been demonstrated to be common in nature. However, precise knowledge regarding interaction between pressures and causative effects of human activities are still lacking.
- **Spatial resolution**: Maps are usually broad-scale and low-resolution. This has considerable implications for precision and accuracy. While low resolution information may be sufficient for setting conservation priorities (see Giakoumi et al. 2015) it cannot be considered appropriate for actual conservation, effective management, and restoration actions.
- **Modelled data**: A number of the maps contain high levels of modelled/predicted data with a great degree of interpolation between actual data points. This has the potential to increase the uncertainty of the information and may limit its utility to policy makers and conservation practitioners. In current maps with modelled data, estimates of uncertainty are rarely provided.
- **Geographic coverage**: In European seas, geographic under-representation is an issue in the current information, both at regional (e.g. Black Sea) and sub-basin (e.g. Eastern Mediterranean Sea) levels.
- **Hotspots of conflict between activities and habitats**: There is a lack of maps which simultaneously identify where high human activity coincides with vulnerable key habitats (important in the planning and geographic positioning of MPAs).
- **Representation of habitats**: Some habitats (e.g. seagrass meadows) have more information than others (e.g. seamounts). This is most likely due to their use by many stakeholders, their perceived or legislative importance, or their accessibility for study.
- **Representation of activities and pressures**: Maps of exogenous pressures are generally lacking. There is a bias in the types of activities and pressures mapped, with a greater focus on resource exploitation activities with a long history (such as fishing or mining) and a lesser emphasis on emergent activities and pressures (such as changes in thermal conditions or noise stemming from new subsea installations such as tidal power).

- **Information availability**: Grey literature (e.g. dissemination publications, technical and project reports) is an important source for useful activities/pressure maps and can expand the knowledge that can be obtained by standard ISI journals; however, these sources are not directly visible or easily retrievable through standard literature platforms.

Based on the above, it is recommended that future mapping initiatives should focus on the following:

- **Generating geo-referenced data**: Open access, geo-referenced data on pressures and activities as well as habitat extent and condition are in high demand for assessments of ecosystem status and health, as well as of cumulative effects. The present study recommends future maps should contain georeferenced information that is easily accessible for use in marine management and conservation efforts.
- **Filling gaps in knowledge**: The study also recommends filling in the geographical and temporal gaps (by digitization of old/historical maps and incorporating fragmented information, e.g. Martin et al. 2014; Telesca et al. 2015) and supporting regional and national mapping initiatives (with dedicated service calls and appropriate funding to compensate for the current trend for reduced government budgets (Borja & Elliott, 2013).
- **Linking habitat, activity, and pressure data:** To better understand how different habitats are affected, or could be affected by pressures, it is necessary to map both habitats and pressures at the same scale and in the same area. This will enable effective conservation and mitigation efforts.
- **Gaining high-level standardization**: The role of transnational and intergovernmental organizations such as the EU, but also OSPAR, HELCOM, UNEP-MAP and the Barcelona and Black Sea commissions, is crucial in the production, standardization, and integration of data with universal approaches and balanced geographical representativeness.

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