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Short Communication

Development and testing of a prototype indicator-based tool for identification of potential problem areas for marine litter in Europe's seas

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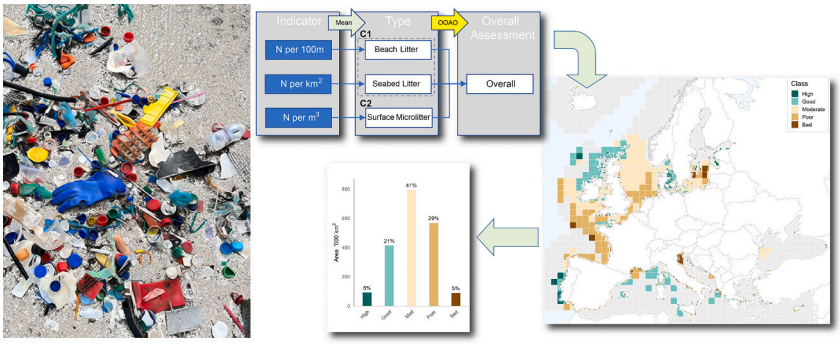
HIGHLIGHTS

- Indicator-based assessment of status for marine litter across Europe's seas
- Data represents beach litter, seafloor litter and floating micro-litter.
- 74.2 % of assessed area found to have 'problem area' status.

GRAPHICAL ABSTRACT



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ABSTRACT

We demonstrate a prototype multi-metric indicator-based assessment tool (i.e. Marine Litter Assessment Tool - MALT) for mapping and identification of 'problem areas' and 'non-problem areas' regarding the occurrence of marine litter in Europe's seas. The study is based on a European-wide data set consisting of three marine litter indicators: (1) litter at the seafloor, (2) beach litter and (3) floating micro-litter. This publicly available data allowed litter status to be determined in 1,957,081 km^2 (19.1 %) of the total area of Europe's seas (10,243,474 km^2). Of the area assessed, 25.8 % (505,030 km^2) was found to be 'non-problem areas' whilst 'problem areas' accounted for 74.2 % (1,452,051 km^2). This indicates that marine litter is a large-scale problem in Europe's seas.

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1. Introduction

For decades, monitoring of the European marine environment has had a focus mainly on (1) biodiversity, (2) contaminants and their effects, (3) nutrients and eutrophication, (4) fish stocks and (5) physical disturbance. Multiple assessment reports by the intergovernmental regional organisations including the Baltic Sea Convention (HELCOM), the North-east Atlantic Convention (OSPAR), the Barcelona Convention (UNEP-MAP), the Bucharest Convention (BSC), the International Council for the Exploration of the Sea (ICES) and the European Environment Agency (EEA) illustrate these priorities, which nowadays may look inadequate given an increased awareness of 'new' threats like climate change, non-indigenous species, overexploitation as well as the topic for this study: marine litter.

For Europe, a turning point for addressing marine litter was the adoption of the European Union (EU) Marine Strategy Framework Directive (MSFD; Anon, 2008) and the associated two Commission Decisions on criteria and methodological standards on the Good Environmental Status of marine waters (Anon, 2010; Anon, 2017). These Decisions specify the 11 MSFD Descriptors and their criteria as determined by the MSFD, including Descriptor 10 'Properties and quantities of marine litter do not cause harm to the coastal and marine environment'.

More recently, the EU has adopted the EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil' (Anon, 2021). The action plan specifies several zero pollution targets to be met by 2030 under EU law, Green Deal ambitions and in synergy with other community initiatives. These targets include reductions of 'plastic litter at sea (by 50%) and microplastics released into the environment (by 30%)'.

Whilst sufficiently robust tools have been developed and used for assessment of eutrophication, for example, any efforts to carry out an integrated assessment regarding the MSFD Descriptor 10 on marine litter have not been disclosed yet, neither by the Regional Seas Conventions (RSC) nor at a pan-European scale. Acknowledging the work on the integrated assessment carried out by for example HELCOM (see HELCOM, 2010, 2018), OSPAR (see OSPAR, 2010) and EEA (2021) focusing on eutrophication, contaminants and/or biodiversity and anchored in the application of multi-metric indicator-based assessment tools, the absence of D10-related assessments may be explained by the lack of quantitative assessment criteria.

Marine litter, in particular its plastic component, has become a major problem for all oceans and seas over the past decades with significant implications for the marine life. Its solution poses a complex and multi-dimensional challenge. EU Member States have, under the MSFD, initiated monitoring of marine litter including microplastics in Europe's seas mostly focusing on litter on beaches, floating at the sea surface, settled on the seafloor or interactions by marine biota. Member States have reported twice to the EU Commission and information on marine litter and microplastics in Member States' marine waters can be found through WISE-Marine (see https://water.europa.eu/marine).

As framed under Descriptor D10, the MSFD requires that 'Properties and quantities of marine litter do not cause harm to the coastal and marine environment'. The four criteria (C) for D10 are the following:

- D10C1: [Macro]-Litter on the coastline, in the surface layer of the water column, and on the seabed.
- D10C2: Micro-litter on the coastline, in the surface layer of the water column, and in seabed sediment.
- D10C3: Micro-litter ingested by marine animals.
- D10C4: The number of individuals of each species which are adversely affected due to litter, such as by entanglement, other types of injury or mortality, or health effects.

For assessment of all or some of these criteria at the EU or Regional Sea Convention (OSPAR: the North-east Atlantic Convention, HELCOM: Baltic Sea Convention, UNEP/MAP: the Barcelona Convention, BSC: the Bucharest Convention) levels, there are several ongoing initiatives, such as undertaken by: MSFD Technical Group – Marine Litter (TG-Litter), ICES (The International Council for the Exploration of the Sea), MEDITS (An international bottom trawl survey in the Mediterranean) Project, EU research projects (EMODNET: European Marine Observation and Data Network, DeFishGear, PERSEUS, EMBLAS, INDICIT: 'Implementation of the indicator of marine litter on sea turtles and biota in RSC and MSFD areas', etc.). With respect to monitoring and application of these criteria, the most progress among marine litter indicators was achieved on beach macrolitter (>2.5 cm), with sufficient data gathered for analyses on establishing baselines and threshold values (Hanke et al., 2019; Van Loon et al., 2020).

After collection of European beach litter data from EU Member States via the EMODnet chemistry module database, harmonisation of data formats and data clean-up, a 2012–2016 dataset, was provided to the MSFD Technical Group on Marine Litter (TG-ML) who derived beach litter baselines at different spatial levels (Hanke et al., 2019). For example, using data collected during 2015–2016 across Europe, the median average beach litter quantity was 149 macrolitter items per 100 m, with different averages for specified regions.

Regarding to the clearcut (i.e. threshold) values for differentiating the good and the bad status, the EU Member States have agreed that any beach must contain no >20 macrolitter items for every 100 m to be stated as 'clean' (Van Loon et al., 2020).

Progress has also been made towards establishing baselines and thresholds for microplastics indicators at the sea surface (Galgani et al., 2019) but has yet to be finalised. The threshold value of only <10 % of the northern fulmars (*Fulmarus glacialis*) exceeding a level of 0.1 g of plastic in their stomach contents is accepted as an OSPAR marine litter indicator (Werner et al., 2020). However, all these efforts mentioned above are all for the individual assessment of each criterion rather than the entire descriptor, D10 Marine Litter.

The monitoring of marine litter and microplastics initiated by the requirements of the MSFD has now generated several pan-European data sets, which in combination with data from research projects (e.g. EMODnet) and citizen science (e.g. Marine Litter Watch; EEA, 2018) may enable an integrated data-driven assessment and subsequent identification of potential 'problem areas' and 'non-problem areas' in terms of marine litter. With this in mind, we have developed, tested and applied a prototype tool for the integrated assessment of marine litter, including microplastics, in Europe's seas.

Despite the adoption of the MSFD in 2008 and dedicated efforts for its interpretation and implementation, assessments of the achievement of the Good Environmental Status for clean, healthy and productive seas in Europe are proven difficult in an integrative way. Key reasons for the absence of a reliable integrated method to assess the environmental status for MSFD's Descriptor 10 on Marine Litter, include the scarcity of good quality data on different marine litter parameters (such as beach litter, sea-bottom litter, microplastics etc) from sufficiently representative areas. Considering the accumulated data from different components of the sea and development in the past decade in relation to integrated assessments for other MSFD Descriptors such as biodiversity (Descriptor 1), eutrophication (Descriptor 5) and contaminants (Descriptor 8), we have developed and tested a simple prototype muti-metric indicator-based assessment tool for marine litter named MALT (Marine Litter Assessment Tool). The justification for our work has not only been access to multiple indicators with reasonable spatial coverage, but also a need by stakeholders, such as the European Environment Agency (EEA), Regional Seas Conventions (RSC) and EU Member States, to identify potential problem areas with respect to marine litter.

Marine litter in Europe's seas has not yet been addressed from a European-wide perspective. However, the European Environment Agency is currently assessing sources, pathways and occurrence of marine litter in Europe (Veiga et al., 2022). The main objective of Veiga et al. (2022) is to assess the situation of marine litter in Europe, particularly the plastic fraction, in a holistic, integrated way. The

assessment takes a life-cycle perspective and covers different environmental compartments, from source to sea. The work will be published as an integrated assessment making use of existing indicators and data sources, which are usually looked at in separate disciplines. For the first time, at a pan-European level, it brings together the domains of production and consumption, waste management and environmental litter pollution. The general ambition is to support a better understanding of the drivers and pressures related to marine litter, and how these relate to the current state and trends of pollution.

A key aim for us, in this study, is the spatial identification of potential 'problem areas' and 'non-problem areas' via integrating litter data from different compartments. Such spatial analyses can not only support the implementation of the MSFD but also contribute in the development and implementation of national or regional Marine Litter Action Plans.

2. Methods

2.1. MALT

The prototype Marine Litter Assessment Tool (MALT) is a multimetric indicator-based status assessment tool. This type of tool has been employed by the EEA and ETC-ICM (The European Topic Centre on Inland, Coastal and Marine waters) in several recent European assessments. These include assessments of status regarding hazardous substances (CHASE+) (EEA, 2019a), eutrophication (HEAT+) (EEA, 2019b), biodiversity, and ecosystem health (MESH+) (EEA, 2021). MALT has been developed using the same principles as these other tools, allowing unified assessments to be made across Europe's seas given varying forms and availability of indicators.

The tool works by calculating an Ecological Quality Ratio (EQR) within a spatial assessment unit (SAU), as an aggregated score of normalised indicator values. All indicator values are normalised to a scale from 0 to 1, with five status classes at equal intervals. This allows indicators using different numerical scales to be compared consistently. To normalise the observed value of the indicator parameter to the common EQR scale, at least three indicator values are required: (1) the threshold value, determining the boundary between good and moderate status i.e. the value of the indicator corresponding to a EQR = 0.6. For example, the value of 20 items per 100 m beach; (2) the value of the indicator corresponding to reference conditions (EQR = 1.0). For example, in the case of a count of items of litter, this could be a maximum of 1 item: (3) the value corresponding to the worst possible case (EQR = 0). For example, for the beach litter indicator, a value of 5129 items per 100 m was used. The indicator values defining the boundary between bad and poor status (EQR = 0.2) and between poor and moderate (EQR = 0.4) were determined by log-linear interpolation of the indicator values corresponding to EQR = 0.0 and EQR = 0.6. Similarly, the indicator value corresponding to EQR = 0.8, the boundary between good and high status was calculated by interpolation between values corresponding to EQR of 0.6 and 1.0.

The full version of the MALT tool was developed with a flexible structure, within which indicators are aggregated at several levels within each assessment unit. Within Descriptor 10, there are two primary criteria (D10C1 Litter and D10C2 Micro-litter) and two secondary criteria (D10C3 Ingestion by animals and D10C4 Individuals adversely affected). The tool was structured with expectations of being able to gather data within three indicator categories, the first two corresponding to C1 and C2 and a third category C3 corresponding to the two biota-related secondary criteria. Its inherent flexibility allows extension of the tool to include C4 and other categories when data is available. The tool aggregates indicator results within different 'types', for example litter on the coastline or litter on the seabed, before aggregating at the Category (Criteria) level. Further subdivision of indicators into subtypes is possible e.g. using separate indicators for plastic and other materials when counting items on the coastline. The potential for aggregation at several levels is a flexible feature which may be useful where more diverse sources of ML monitoring data are to be gathered to give a single assessment.

In the present study, the available data represented three types of litter, two within C1: (1) litter on the coastline, (2) litter on the seafloor and a third in C2: (3) micro-litter in the surface layer of the water column. Here with three types of litter a simplified structure was adopted (Fig. 1). EQR values were calculated for each of the three indicators and using a one-out all-out method (OOAO), the overall EQR is determined as the worst of the EQR values of the three indicators. Annex 2 outlines the structure of the full tool. There is no requirement for data for all indicators to be available in all assessment units. An aggregated result is calculated for each assessment unit having data for at least one indicator. This is true for version applied here as well as the full version described in Annex 2. Other software tools are then used to visualise results and to summarise them across all assessment units and within regions.

The MALT tool is intended to be applied using indicators mapped to the EEA assessment grid which was used as the spatial structure for the previous Europe-wide EEA assessments mentioned above. However, in principle, the tool can be applied to any set of spatial assessment units (SAUs), with the only requirement being that all indicators are mapped consistently to the same set of SAUs. That is, indicators defined with different spatial resolutions and extents should be interpolated to a common set of spatial assessment units.

2.2. Data sources

The observed beach litter item counts used in the assessment were derived from three sources: (1) EEA Marine Litter Watch (MLW; www.eea.europa.eu/themes/coast_sea/marine-litterwatch, see Kideys and Aydın, 2020a, 2020b and Kideys et al., 2021), (2) OSPAR Beach Litter Database (https://odims.ospar.org/en/search/?datastream=marine_litter_beach_monitoring; beachlitter.ospar.org/list) and (3) EMODnet Chemistry (www.emodnet-chemistry.eu/marinelitter). The MLW data contained observations from 2013 to 2021 covering 1424 individual beaches whilst the OSPAR data covered 124 beaches from 2012 to 2018. EMODnet data contained observations from 2010 to 2020 at 1225 beaches. There is some overlap between the datasets. All of the OSPAR observations were found to be included in the EMODnet dataset whilst 664 beaches were included in both EMODnet and MLW datasets. Where several litter item counts were made on the same beach on different dates, the median of the counts was used. For the seafloor litter indicator, all data was provided by EMODnet Chemistry.

The seafloor litter data were extracted from the EMODnet dataset 'European seafloor litter standardized, harmonized and validated datasets 2006/2021 v2021'. The extracted dataset used for the analysis covers 20,551 surveys at 20,021 sites in 22 countries, taken in the period 2010–2021. The surveys included in the dataset were done by their respective marine litter projects: MEDITS, EVHOE, Baltic International Trawl Survey, DeFishGear, Demersal Young Fish Survey, IBTS, North Sea Beam Trawl Survey, and PROMARE. The floating micro-litter data were extracted from the EMODnet dataset 'European floating micro-litter standardized, harmonized and validated datasets 2011/2020

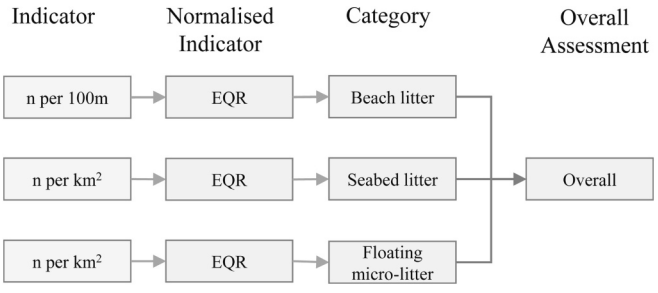

Fig. 1. MALT assessment indicator aggregation scheme.

v2021'. The extracted dataset used for the analysis covers 839 trawl surveys used on 60 cruises in the period 2011–2020.

Although the MALT tool is designed to integrate multiple indicators, this preliminary assessment is based on the use of three indicators: (1) the count of beach litter items per 100 m of beach, (2) the count of seafloor litter items per km^2 and (3) the count of micro-litter in the surface of the water column per km^2. It is preferable to apply indicators with respective published threshold values. In the case of the beach litter count, we applied the threshold value of 20 items per 100 m published by Van Loon et al. (2020). For the seafloor litter count, no published threshold values were found. Here we applied the 15th percentile of the counts of seafloor litter in the assessment dataset. This method is therefore analogous to the method used to derive the beach litter threshold. A UNEP/MAP report (2015) on marine litter in the Mediterranean Sea suggests a baseline range of 200,000–500,000 per km^2 for floating micro-litter. We have tentatively applied the lower value of 200,000 per km^2 as the threshold in this assessment.

2.3. Study area

The testing of MALT has been carried out across Europe's seas. Assessment Units are defined by the European Environment Agency (EEA, 2021), with an assessment unit of 20 × 20 km along the shores and an assessment unit of 100 × 100 km offshore (see Supplementary Material for a map of the assessment units). Marine regions are (1) the Baltic Sea (see www.helcom.fi), (2) the North-east Atlantic Ocean (see www.ospar.org), (3) the Mediterranean Sea (see www.unep.org/unepmap) and (4) the Black Sea (see www.blacksea-commission.org).

3. Results

Of all the marine regions assessed, also having the smallest area, the Baltic Sea had the best spatial coverage for marine litter data among the assessed European seas (Fig. 1). Assessment results were calculated for grid cells covering 172,926 km^2 (43.4 %) of the 398,220 km^2 covered by assessment grid cells. Within the assessed cells of the Baltic Sea, 17.4 % (30,130 km^2) had a 'High' or 'Good' status whilst 82.6 % (142,796 km^2) had a status of 'problem area' (i.e. 'Moderate', 'Poor' or 'Bad') with respect to marine litter (i.e. beach and seafloor litter).

The marine litter data from the North-east Atlantic Ocean had spatial coverage of 22.0 % (1,505,214 of 6849,267 km^2). In this region 22.3 % (336,027 km^2) of total area showed 'High' or 'Good' levels. However, 77.7 % (1,169,186 km^2) of the North-east Atlantic Ocean were still classified as having 'Moderate', 'Poor' or 'Bad status'.

Though not the region with the worst coverage, coverage in the Mediterranean Sea was relatively low. Only 9.7 % (243,481 km^2) out of 2,520,934 km^2 were assessed here. However, with 56.7 % (3252 km^2) of the assessed area classified as having 'High' or 'Good' status, this region

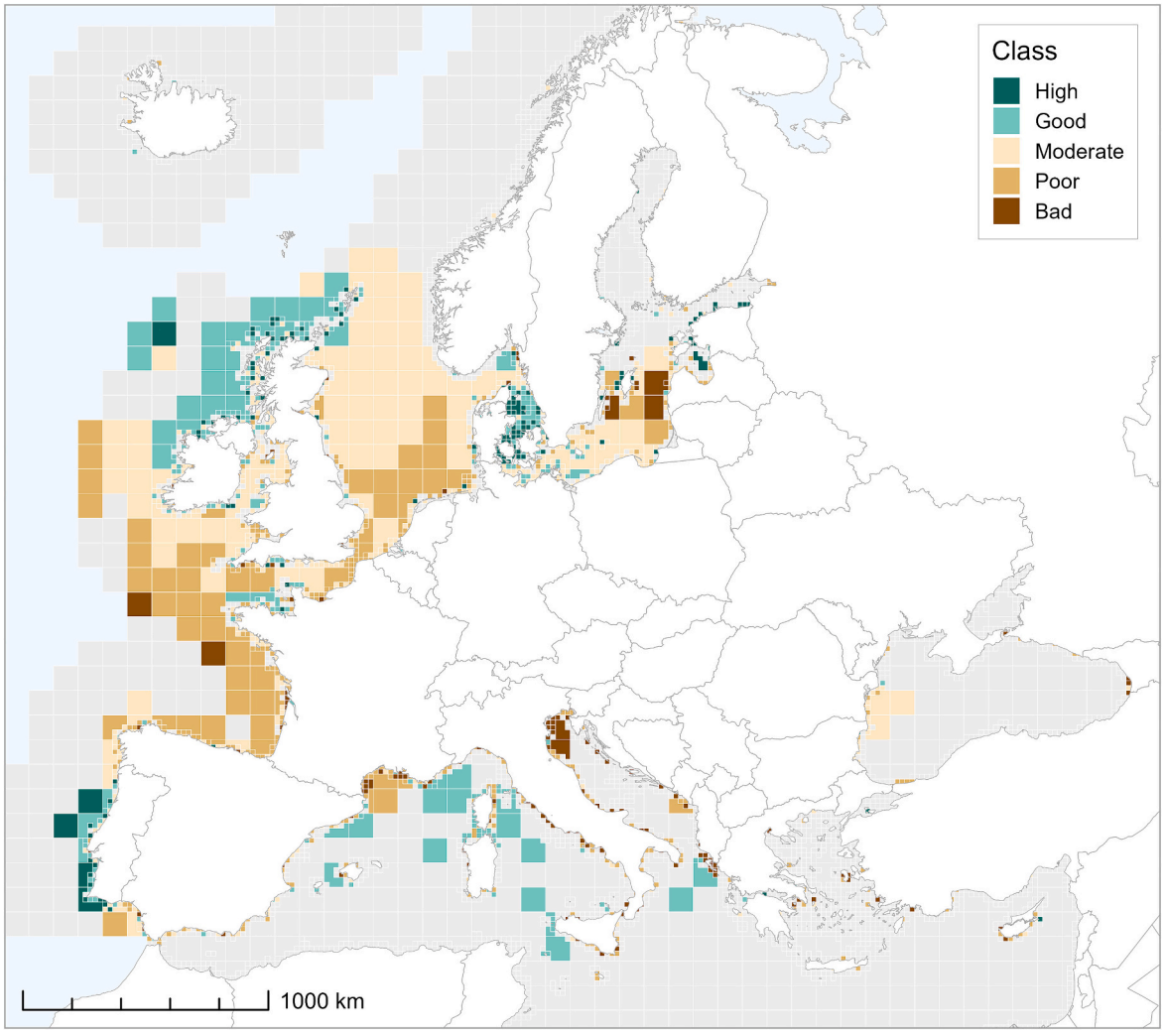

Fig. 2. Preliminary classification of integrated status with respect to marine litter in Europe's seas. Areas classified as 'High' and 'Good' are Identified as 'non-problem areas' whilst 'Moderate', 'Poor' and 'Bad' are identified as 'problem areas.' See Supplementary Material for detailed maps.

had the highest percentage of "non-problematic areas" (i.e. high and good), whilst 'Moderate', 'Poor' or 'Bad' status were estimated as 43.3 % (105,376 km^2) of the assessed areas (Fig. 2).

The Black Sea was the region with the poorest coverage for marine litter data. Grid cells covering only 7.5 % (35,460 out of 475,054 km^2) were assessed. This region also had the lowest fraction of assessed area judged to be in 'High' or 'Good' status (only 2.2 % or 767 km^2 of the assessed area), whilst 97.8 % (34,693 km^2) had a status of 'Moderate', 'Poor' or 'Bad'.

Considering the entirety of Europe's seas, 19.1 % (1,957,081 out of 10,243,474 km^2) of the grid cells were covered by the assessment (Fig. 3). The fractions of the assessed area in 'High' or 'Good', status was 25.8 % (505,030 km^2) whilst 'Moderate', 'Poor' or 'Bad' status accounted for 74.2 % (1,452,051 km^2).

In coastal grid cells the fraction of assessed area achieving 'non-problem' status was lowest in the Black Sea with 7.5 % (767 of 10,260 km^2 assessed), though this was also the region where the fraction of coastal area assessed was lowest (9.3 %). The Mediterranean Sea had 21.5 % 'non-problem' area (19,705 of 91,481 km2 assessed). The Baltic Sea (37.7 % or 24,930 of 66,126 km^2) and the North-east Atlantic Ocean (35.7 % or 82,427 of 230,814 km^2) had similar fractions of 'non-problem' areas. Overall, the fraction of coastal areas classified as 'non-problem' areas was 25.5 % (see Fig. 4A).

Considering the whole of Europe's seas, the fraction of offshore areas determined to have a 'non-problem' status (24.2 %) was not dissimilar to the coastal fraction (see Fig. 4B). Again, the Black Sea was the region with the worst result, and none of the assessed areas were classified as 'non-problem' area. The coverage was also lowest among the four regions (6.9 %). The Baltic Sea and North-east Atlantic Ocean were found to have only, respectively, 4.9 % and 19.9 % of their assessed areas achieving 'non-problem' status. The region showing the greatest difference between offshore and coastal assessment results was the Mediterranean Sea where 77.9 % of the assessed area was found to have 'non-problem' status. It should be noted that the area included in the assessment represented only 9.7 % of the total area of the region.

Focusing on individual indicators, for beach litter, considering coverage only in relation to coastal grid cells, the fraction of assessed area varied from 7.2 % in the Black Sea to 11.4 % in the Baltic Sea. Results were poorest in the Black Sea and Mediterranean Sea with, respectively 6.0 % and 9.6 % of assessed area classified as 'non-problem'. The proportion of 'non-problem' area in the North-east Atlantic Ocean was 13.7 % and in the Baltic Sea it was 32.3 % (Fig. 5A).

The seafloor status varied from 0 % of the assessed area having a 'non-problem' status in the Mediterranean Sea and 1.4 % in the Black Sea to 12.9 % in the Baltic Sea and 22.4 % in the North-east Atlantic Ocean (Fig. 5B). The assessment coverage was only 2.1 % in the Mediterranean Sea reaching 37 % in the Baltic. The overall result was that 20.5 % of assessed area was classified as 'non-problem' with respect to seafloor litter.

For floating micro-litter, no data was available for the Black Sea. For the other regions coverage varied from 3.8 % in the Baltic Sea to 6.6 % in the Mediterranean Sea. The results show, perhaps surprisingly, that none of the assessed areas in the Baltic Sea and the North-east Atlantic Ocean were determined to be 'problem areas' with respect to floating micro-litter. In fact, all of the assessed areas in the Baltic were determined to have 'High' status. The only 'problem areas' were found in the Mediterranean Sea but these accounted for only 0.6 % (945 km^2) of the area assessed (Fig. 5C).

4. Discussion and conclusions

An indicator is a measure of the 'state' of the environment. The selection of indicators and the accompanying monitoring methods depend on the scientific or policy questions being addressed for the environmental, social and economic considerations. Indicators are also essential in evaluating the effectiveness of mitigation measures. Environmental indicators proposed should be (a) scientifically valid, (b) simple to understand by the public and policy makers, (c) sensitive and responsive to change, (d) cost-effective, and (e) policy relevant (UNEP, 2016). The MALT tool meets these five criteria and could be a suitable index for spatial assessment marine litter in an integrated manner.

However, the MALT tool should be seen as a prototype and a first effort to map potential problem areas for marine litter at a European scale. The results should be regarded as interim due to a few shortcomings: (1) the spatial coverage of the monitoring, (2) the limited number of operational marine litter indicators under the MSFD, (3) the

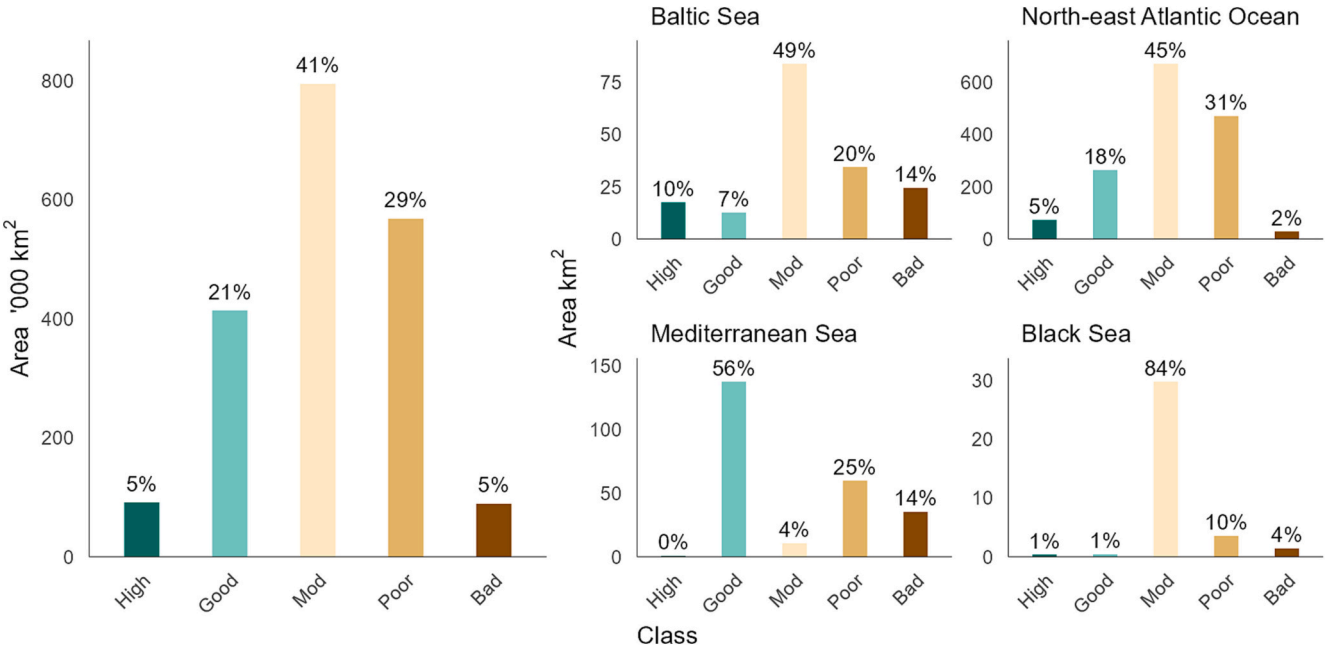

Fig. 3. Sum of areas by assessed integrated status class. Areas classified as 'High' and 'Good' are identified as 'non-problem areas' whilst 'Moderate' (labelled 'Mod'), 'Poor' and 'Bad' are identified as 'problem areas' with respect to marine litter. Summaries are shown for all areas (left) and the four regions of the Baltic Sea, North-east Atlantic Ocean, Mediterranean Sea and Black Sea. Percentages indicate the area for each class relative to the area assessed.

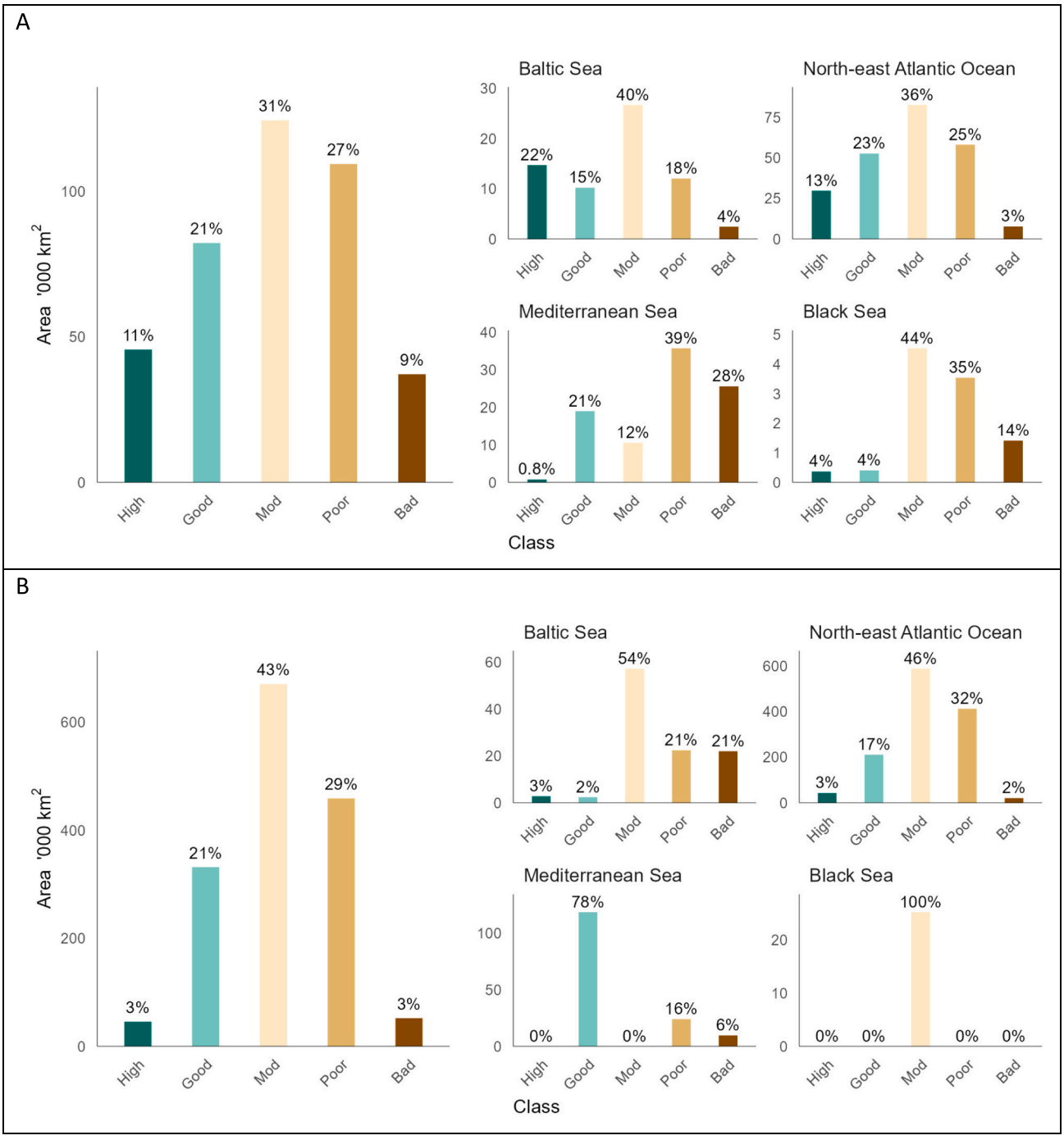

Fig. 4. Panel A: Summary MALT integrated status, coastal areas (20 km grid cells). Panel B: Summary MALT integrated status, offshore areas (100 km grid cells). Within each panel, areas are summed for each status class. Areas classified as 'High' and 'Good' are identified as 'non-problem areas' whilst 'Moderate' (labelled 'Mod'), 'Poor' and 'Bad' are identified as 'problem areas' with respect to marine litter. Summaries are shown for all areas (left) and the four regions of the Baltic Sea, North-east Atlantic Ocean, Mediterranean Sea and Black Sea. Percentages indicate the area for each class relative to the area assessed.

scarcity of data on different MSFD criteria and sub-criteria, and(4) the status of the threshold values used for the demonstration. The potential weakening of confidence in the assessment which might result from the application of untested threshold values must be balanced with the desire to achieve the greatest possible assessment coverage in terms of available types of litter data. As better threshold values become available from different criteria, these can easily be incorporated, replacing the values employed here. Also, as thresholds become available for other marine litter metrics (e.g. for microplastics) or more specific thresholds e.g., within different categories of beach litter, these indicators can be integrated into the MALT assessment procedure with minimal effort.

The fraction by area of assessment units (19.1 %) where it was possible to determine the status of marine litter can be considered a reasonable proportion. The inclusion of litter counts in the assessment units where status is absent would improve the quality of the assessment. In particular, the coverage in the Mediterranean Sea and Black Sea is somewhat poorer than the other regions. Another important improvement required is the inclusion of further indicators for other categories of litter in the MALT assessment.

The results showed that no areas were determined to have a problem

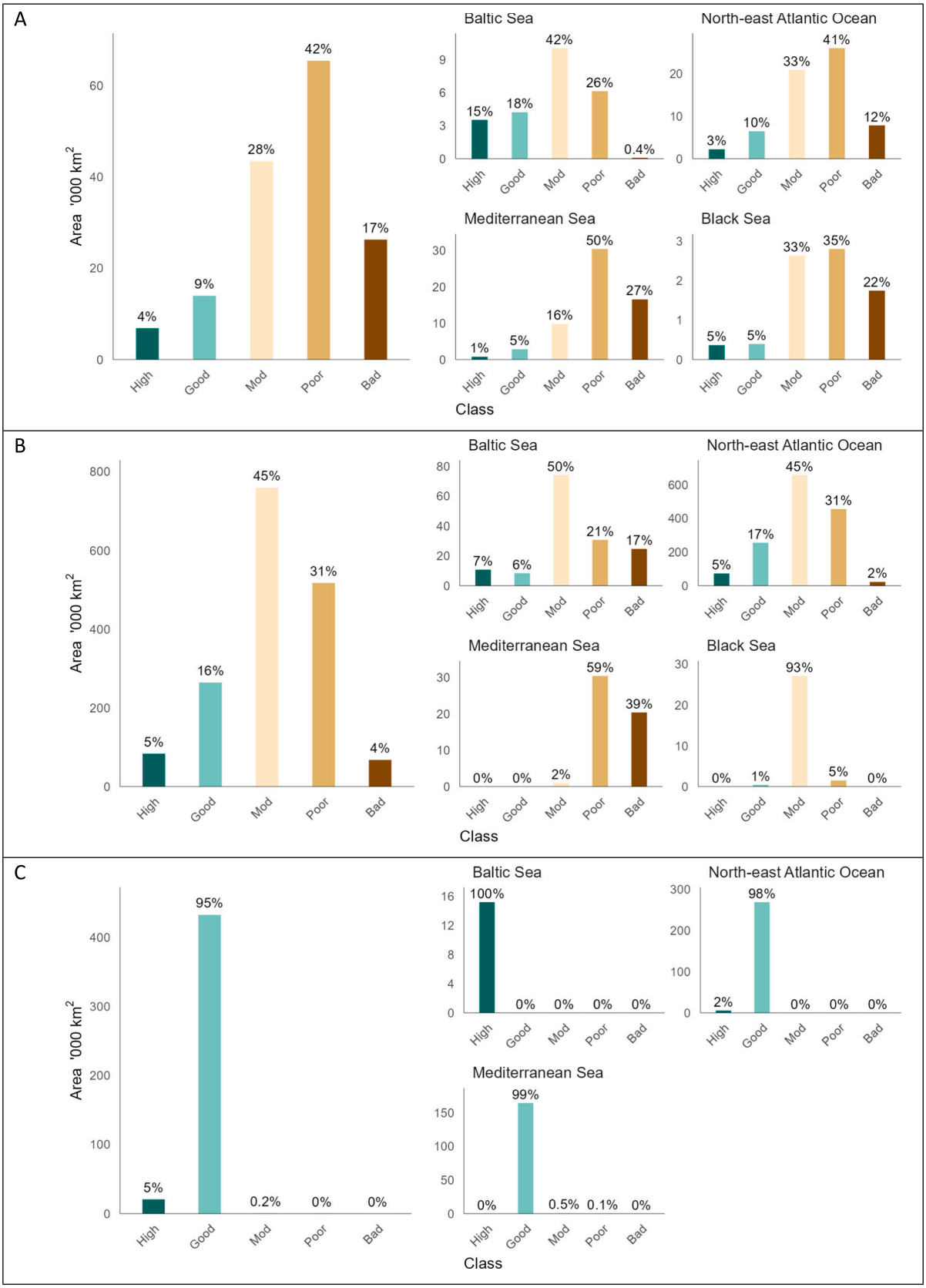

Fig. 5. Panel A: Summary beach litter status. Panel B: Summary seafloor status. Panel C: Summary floating micro-litter status. Within each panel, areas are summed for each status class. Areas classified as 'High' and 'Good' are identified as 'non-problem areas' whilst 'Moderate' (labelled 'Mod'), 'Poor' and 'Bad' are identified as 'problem areas' with respect to marine litter. Summaries are shown for all areas (left) and the four regions of the Baltic Sea, North-east Atlantic Ocean, Mediterranean Sea and Black Sea. Percentages indicate the area for each class relative to the area assessed.

regarding floating micro-litter. The question should be raised as to whether this result is a true reflection of the status with respect to this particular type of litter and whether the tentatively applied threshold value of 200,000 items per km^2 for floating micro-litter is representative of the level at which pollution by micro-litter can be considered to be problematic.

Comparing the classifications between the four regional seas reveals some very specific differences which cannot be explained by variations in monitoring, but almost certainly relate to different waste management practices or, in some places, to long-range transport of marine litter.

Despite its limitations, we consider the application of a prototype tool is better than having no tool at all and that our interim results are useful for the identification of 'problem areas' and 'non-problem areas' for the occurrence of marine litter in Europe's seas. Our results indicate that the Black Sea region had the poorest status in terms of marine litter among the regional seas investigated This result agrees with previously European level undertaken assessments (Kideys and Aydın, 2020a, 2020b; Kideys et al., 2021). The reason for high values in the Black Sea was suggested to be due to the continuous input from some hot spots, such as high number of rivers as well as remnants of solid waste depositions in some areas along the coast (Kideys et al., 2021).

The MSFD was adopted in 2010 and despite two EU Commission Decisions from 2010 and 2017, respectively, only a few marine litter indicators with agreed threshold values currently exist. Common concepts for setting threshold values do exist and should be applicable on national or regional scales. Why this has not yet led to the development of more operational marine litter indicators can probably be explained by the fact that the setting of threshold values is both a scientific and political process and that stringent threshold values would require potentially expensive management measures to be implemented.

This study should be seen as the first step towards a fully harmonized and coordinated assessment of GES for MSFD Descriptor 10. Our results are as good as they can get given the monitoring activities of EU Member States according to the MSFD. We believe the MALT tool is a useful supplement to the MSFD assessment requirements and a tool that both Regional Seas Conventions and Member States could apply the MALT methodology in future assessments and thus contribute to wider use and potentially also a co-development, especially with respect to the inclusion of a confidence assessment. Regardless of the added value of MALT, there is no doubt that the quality of monitoring networks ought the be improved, both with respect to spatial and temporal coverage. In this study, there are large areas, especially in the northern Baltic Sea, Mediterranean Sea and Black Sea, with poor coverage.

We conclude the following: (1) 'Non-problem areas' was found to cover 505,030 km^2 (25.8 %) whilst 'problem areas' accounted for 74.2 %, (2) the application of MALT and the results may support not only the implementation of the MSFD, but also to support a succeeding development and implementation of national or regional Marine Litter Action Plans, and (3) there is room for improvement, especially regarding the development of additional marine litter indicators and their threshold values.

Based on these conclusions, we judge that MALT has strengths and weaknesses, but our study documents that Europe has a large-scale problem regarding the occurrence and densities of marine litter in both coastal and offshore waters. Hence, implementation of the EU Zero Pollution Action Plan as well as action plans by Regional Seas Conventions is important. Without dedicated actions to improve the management of litter and waste from both sea-based and land-based sources, and reducing inputs to the marine environment, there are limited chances that Europe's seas will achieve a Good Environmental Status with respect to MSFD D10 in the foreseeable future.

CRediT authorship contribution statement

Ciaran J. Murray: Conceptualization, Data Curation, Methodology, Analysis, Writing - Original Draft, Writing - Review & Editing.
Bert van Bavel: Writing - Review & Editing.
Ahmet E. Kideys: Data Curation, Writing - Review & Editing.
Amy L. Lusher: Writing - Review & Editing.
Johnny Reker: Conceptualization, Writing - Review & Editing.
Gašper Šubelj: Data Curation, Writing - Review & Editing.
Jesper H. Andersen: Conceptualization, Writing - Original Draft.

Declaration of competing interest

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Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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