NEA PANACEA Task 3.5: Evaluate the Use of the Extent of Physical Disturbance Indicator (BH3a) and Other OSPAR Information to Guide Assessment of Effectiveness of Management Measures

Introduction

Marine Protected Areas (MPAs) have been used globally for several decades to protect and conserve marine species and habitats (Wells, *et al.,* 2016). Several international agreements have driven the recent global expansion of MPA networks. The United Nations Convention on Biological Diversity (CBD) Aichi Target 11 aimed to conserve 10% of the worlds coastal and marine areas by 2020, through protected areas and other effective area-based conservation measures (OECMs) as part of the Strategic Plan for Biodiversity 2011-2020 (CBD, 2020). The Post-2020 global biodiversity framework has built on existing targets with the ‘30 by 30' target, which aims to ensure that 30% of land and sea areas are conserved through protected areas and OECMs (CBD, 2021). Furthermore, within the North-East Atlantic, OSPAR ministers adopted Recommendation 2003/3 on a network of marine protected areas in 2003 (OSPAR, 2023), which aimed to establish an “ecologically coherent network of MPAs in the North-East Atlantic that is well managed by 2016” (OSPAR, 2023).

MPAs have different levels of protection and aims, specific to the underpinning types of national or international legislation that they were designated under. In the North-East Atlantic, OSPAR MPAs have three aims: to provide protection, as well as conserve and restore species, habitats and ecological processes that have experienced adverse anthropogenic pressures; follow the precautionary principle to prevent degradation and damage to species, habitats and ecological processes; and to protect and conserve the maritime area that best represents the range of species, habitats and ecological processes within it (OSPAR, 2023).

MPAs are not the only spatial measures for the protection of habitats and species. OSPAR has also be working on other measures, such as those under the protection of Threatened and / or Declining species and habitats, and OECMs. These measures have not been included in the current assessment, but they could be added in future if evaluation of effectiveness using indicator-based assessments are needed.

Marine environments, including MPAs, are subject to diverse pressures from a range of human activities. However, fisheries, especially those with mobile bottom-contacting gears (hereafter referred to as bottom-contact fisheries), have been widely documented as one of the most wide-spread sources of anthropogenic pressures to affect marine environments, globally (Halpern, *et al.,* 2008; OSPAR, 2010; Foden, *et al.,* 2011; Matear, *et al.,* 2023). Bottom-contact fisheries can have detrimental effects on marine environments through physical disturbance to the seafloor, the degree of which varies depending on the penetration depth of the fishing gear, the intensity of fishing, and the underlying species and habitats affected (Collie, *et al.,* 2001; Kaiser, *et al.,* 2006; Eigaard, *et al.,* 2015; van Denderen, *et al.,* 2015; Hiddink, *et al.,* 2017; OSPAR, 2017).

Within the OSPAR indicator framework, the OSPAR Common Indicator BH3a (Extent of Physical Disturbance to Benthic Habitats: Fisheries with mobile bottom-contacting gears) is an assessment method designed to estimate physical disturbance caused by bottom-contact fisheries. The BH3a method takes into consideration the diverse impacts of various gear components and fishing intensity caused by bottom-contact fisheries at both the surface (gear components penetrating less than 2 cm) and subsurface (gear components penetrating 2 cm or more) of the seabed. The BH3a method quantifies the distribution and intensity of surface and subsurface abrasion pressure using spatial layers derived from vessel monitoring system (VMS) and logbook data, provided by the International Council for the Exploration of the Sea (ICES). This information is combined with the sensitivity - in terms of resistance (ability to withstand change) and resilience (ability to recover) - of underlying species and habitats to surface and subsurface abrasion pressure from bottom-contact fisheries, to estimate disturbance (Matear, *et al.,* 2023). The indicator method has widespread application throughout the North-East Atlantic and is agreed as an OSPAR Common Indicator in: Region II (Greater North Sea), Region III (Celtic Seas), and Region IV (Bay of Biscay and Iberian Coast). Furthermore, seafloor disturbance associated with bottom-contact fisheries was assessed using the BH3a indicator in the OSPAR Quality Status Report (QSR), 2023 (Matear, *et al.,* 2023).

Indicator outputs, such as BH3a, could improve understanding of the extent and distribution of disturbance within and across OSPAR MPAs. Such understanding could inform the future direction of the MPA Network and evaluate its contribution to the reduction of the extent and distribution of disturbance to the seafloor caused by anthropogenic activities. Assessments of the extent and distribution of seafloor disturbance in conjunction with spatial measures (e.g., MPAs) have not yet been conducted within the OSPAR framework. Therefore, this assessment builds on work undertaken in the QSR 2023 by analysing BH3a outputs in conjunction with the location of MPAs designated for habitat and species features within the OSPAR MPA Network. Analyses aimed to quantify differences in the extent and intensity of disturbance within and outside the MPA Network, and any trends, to understand the extent to which BH3a can be applied to assess seafloor disturbance in protected areas designated for conservation importance. However, it should be noted that a full evaluation of management measures agreed within MPAs at a national or OSPAR Regional-level was not possible at this stage due to the lack of spatial information on agreed management measures within specific MPAs.

Materials and Methods

Data Sources and Data Preparation

Estimates of physical disturbance from bottom contact fisheries in the OSPAR maritime area were obtained from spatial outputs of the OSPAR QSR 2023 BH3a indicator assessment (Matear *et al.,* 2023). Disturbance estimates were provided in the form of categories ranging from 0-9, for individual habitat polygons within ICES 0.05 x 0.05-degree c-squares, based on bottom-contact fishing pressure data between the years 2009 and 2020. Disturbance estimates were available for each individual year between 2009 and 2020, as well as estimates based on aggregated pressure for the following temporal ranges: 2009 to 2020 (QSR 2023 assessment period) and 2016 to 2020 (MSFD assessment period). Furthermore, disturbance data were available for the following benthic assessment units where BH3a is agreed as a Common Indicator: Faroe Shetland Waters, Central North Sea, Southern North Sea, Channel, Norwegian Trench, and Kattegat (OSPAR Region II: Greater North Sea); Northern Celtic Sea, and Southern Celtic Sea (OSPAR Region III: Celtic Seas); Gulf of Biscay, North-Iberian Atlantic, South-Iberian Atlantic, and Gulf of Cadiz (OSPAR Region IV: Bay of Biscay and Iberian Coast). Disturbance data were also available for the Atlantic

Projection (OSPAR Region V: Wider Atlantic) where BH3a is a Candidate Indicator. For full details on the methodology for estimating disturbance from bottom-contact fisheries using the BH3a indicator please see Matear *et al.,* (2023).

Spatial boundaries for MPAs within the OSPAR Network as of July 2021 were obtained from the OSPAR Data and Information Management System (ODIMS) in ESRI Shapefile format (OSPAR, 2021b). The Shapefile contained polygons for 551 nationally designated MPAs submitted to the OSPAR Network by Contracting Parties with unique World Database on Protected Areas Identifiers (WDP ID). To ensure MPA presence aligned with the temporal range of the pressure data used in the BH3a assessment (2009 to 2020), the Shapefile was checked for MPAs designated or proposed to the OSPAR Network between 2020 and 2021 using R Statistical Software (v3.6.1; R core Team, 2019), specifically the 'sf' (Pebesma, 2018) and 'tidyverse' packages (Wickham, *et al.,* 2019). Four sites were identified as being proposed in 2020 and no new sites were proposed in 2021.

All sites proposed to the OSPAR MPA Network in 2020 were retained in analyses, as areas within these sites were included within the OSPAR MPA Network prior to 2020. Of the MPAs submitted in 2020, West of Scotland was the only entirely new site (i.e., other sites were updated but existed in the MPA Network prior to 2020). However, national designation of the West of Scotland MPA in September 2020 resulted in the revocation of Rosemary Bank Seamount which was previously designated within the site prior to 2020 (Marine Scotland, 2020), and therefore was included in this assessment.

Details of the designated features present within OSPAR MPAs were not readily available in the aforementioned MPA Network Shapefile and, therefore, were obtained separately from the OSPAR MPA database (OSPAR, 2021c). The MPA feature data contained designated features for each MPA, alongside the MPA WDP ID, as submitted by OSPAR Contracting Parties. The features were grouped in separate columns for habitat and species features, respectively.

Analyses

Combining MPA Features with MPA Boundaries

Prior to submission to the OSPAR MPA Network, MPA designations are made under different types of national and international legislation for the protection of variety of different features (grouped under habitats or species in the OSPAR MPA Database). Therefore, the same location might have multiple, overlapping designations, and as a result, the boundaries of certain parts of the MPA Network had spatial overlaps (Figure 1). Furthermore, MPAs with species features alone typically included transient species (such as fish, mammals, and marine birds) which are not typically assessed for disturbance from bottom-contact fishing gears using the BH3a indicator. Therefore, to understand the proportion of the MPA Network where an assessment of disturbance to benthic habitats via BH3a was most relevant, the total area of the MPA Network containing habitat features was identified. Additionally, to avoid overestimating the extent of the MPA Network, polygon overlaps were resolved.

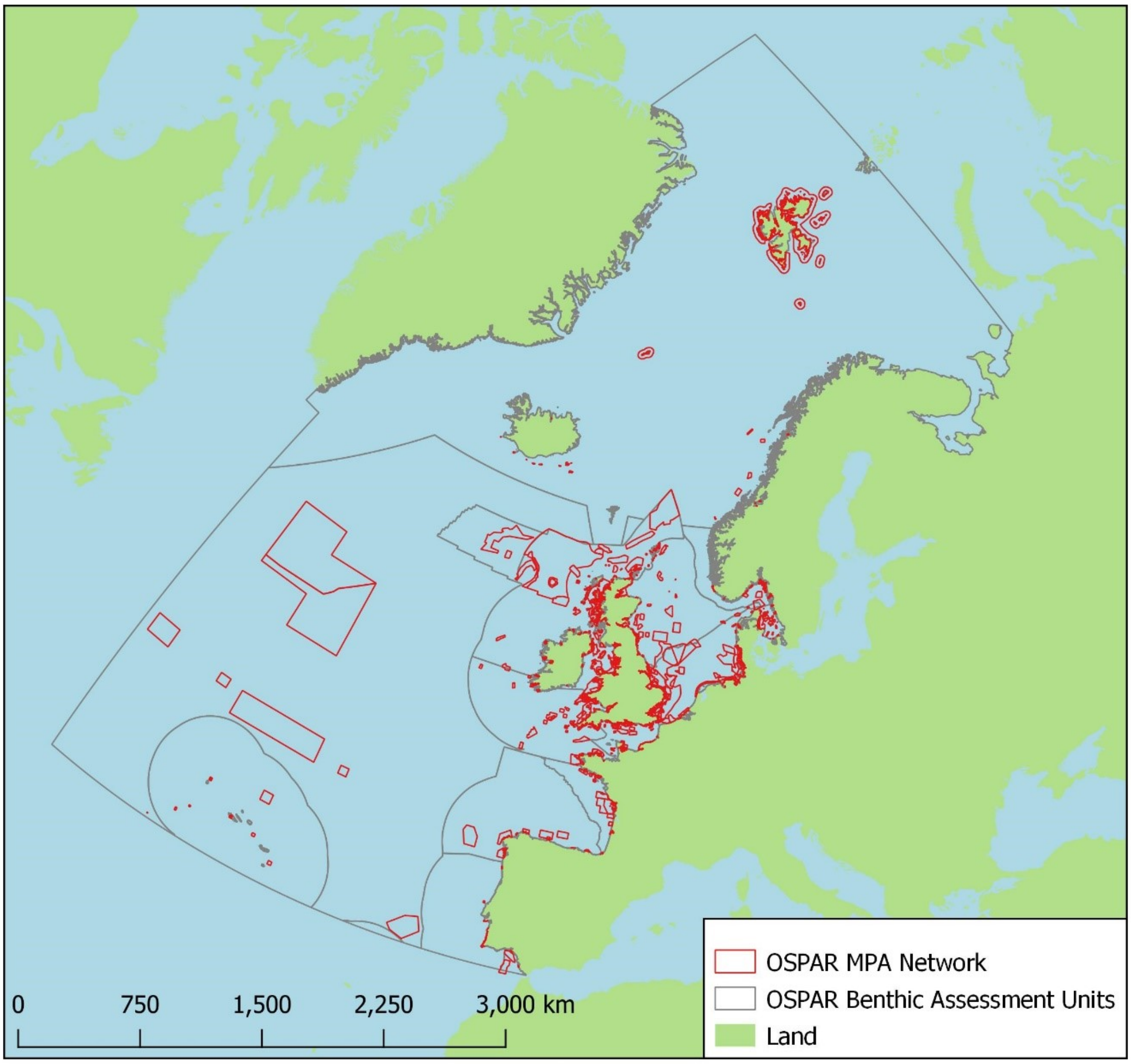

Figure 1: Extent and distribution of the OSPAR MPA Network as of July 2021, prior to geoprocessing.

To identify the spatial extent of the OSPAR MPA Network designated for different features, and resolve spatial overlaps, spatial analyses were undertaken in QGIS v3.16.5 (QGIS Development Team, 2021). The OSPAR MPA Shapefile was reprojected from the World Geodetic System (WGS) 1984 Web Mercator Auxiliary Sphere projected coordinate system to the WGS 1984 geographic coordinate system to facilitate spatial assessments. The ‘Polygon self-intersection’ tool was then used to create separate features from the areas of MPA polygons that overlapped, with associated metadata indicative of WDP ID codes from the relevant overlapping MPAs. The attribute table was exported from QGIS and analysed in R, and the features associated with each WDP ID code present in each polygon were checked to ensure the following information was recorded in a new column:

- All polygons containing WDP ID codes with habitat features present in the MPA feature data were identified.
- Where WDP ID codes with habitat features were absent, the remaining polygons with WDP ID codes with species features in the MPA feature data were identified.
- Where both habitat and species features were absent, it was determined the remaining polygons had no features present in the OSPAR MPA feature data.

Data were subsequently exported from R and re-joined to the attribute table of the polygon self-intersection layer in QGIS. To resolve overlapping polygons, the layer was then

‘Dissolved’ and erroneous geometries were fixed. The final layer for the MPA network contained three multipolygon features comprising the following areas within the benthic assessment units assessed by BH3a (Figure 2):

- Area within MPAs with habitat features in the OSPAR MPA database.
- Area within MPAs with species features only in the OSPAR MPA database.
- Area within MPAs with no species or habitat features submitted to the OSPAR MPA database.

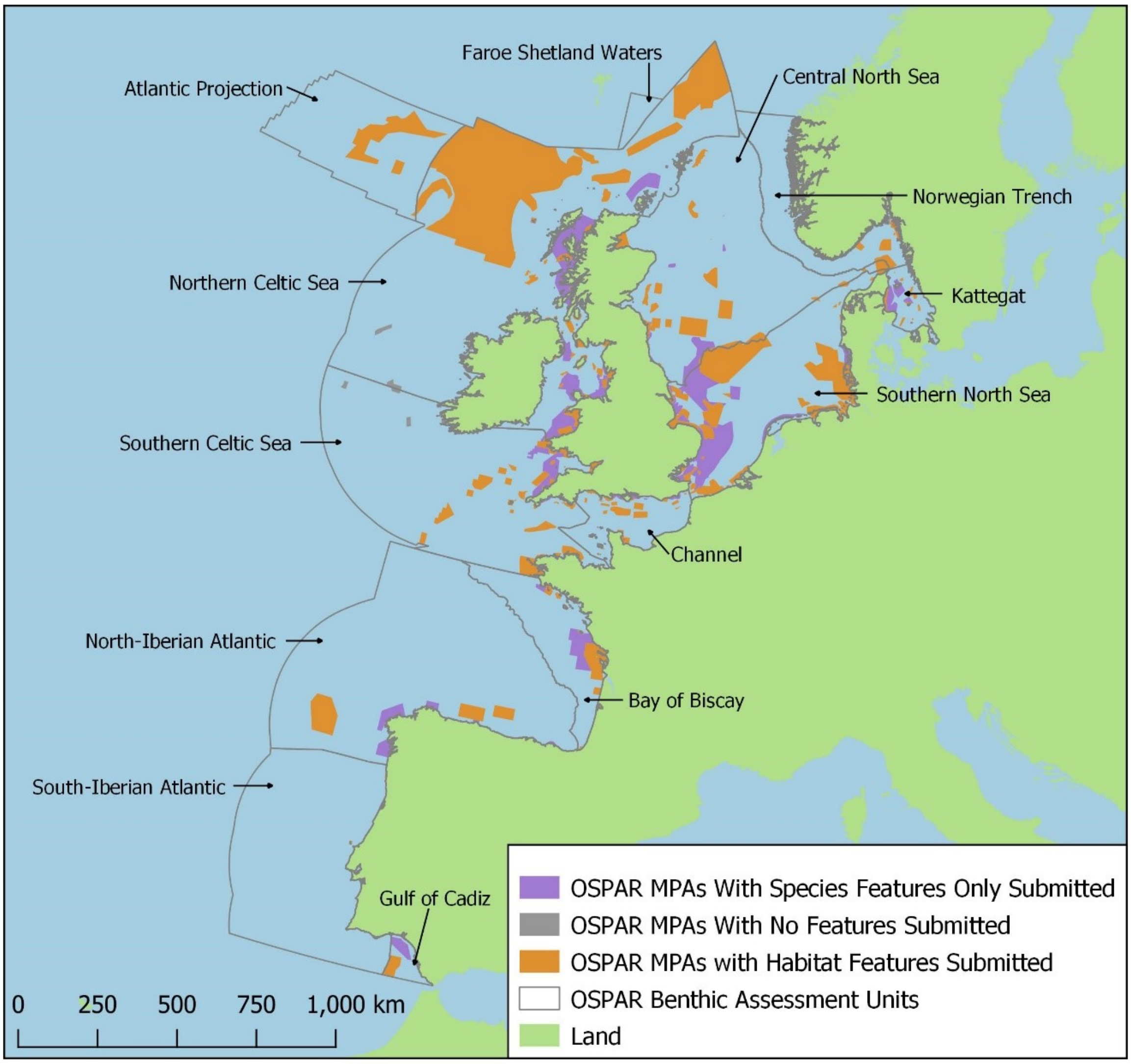

Figure 2: Marine Protected Areas of the OSPAR MPA Network, within BH3a common and candidate assessment units. MPAs are classified by designated feature: purple – OSPAR MPAs with species features only; grey – OSPAR MPAs with no features; and orange – OSPAR MPAs with habitat features.

Estimating Disturbance Within and Outside the OSPAR MPA Network

Further spatial analyses using the disturbance data obtained from the QSR 2023 BH3a indicator assessment and the dissolved OSPAR MPA Network layer was carried out in ArcGIS v10.1 (ESRI, 2012) to estimate the distribution and intensity of disturbance within and outside OSPAR MPAs, geoprocessing was undertaken at a benthic assessment unit scale. To obtain estimates of disturbance within the spatial boundaries of the MPA Network the ‘Intersect’ tool was used. To obtain estimates of disturbance outside OSPAR MPAs, the

‘Erase’ tool was used to remove the area corresponding to MPAs from the BH3a disturbance data. The QGIS ‘Fix geometries’ and ‘Delete duplicates’ tools were subsequently used on intersected and erased disturbance layers to repair invalid geometries that occurred as a result of geoprocessing. To enable area to be calculated, all intersected and erased disturbance layers were reprojected into ETRS 1989 Lambert Azimuthal Equal Area (LAEA) projected coordinate system.

For the analyses of disturbance within and outside the OSPAR MPA Network using BH3a results, disturbance categories (ranging from 0 to 9) were grouped following the same methodology used in the OSPAR QSR 2023 (Matear *et al.,* 2023). The disturbance groups were applied to all individual years and were as follows: ‘Zero’ = no reported VMS data or Swept Area Ratio (SAR) value of 0 reported; ‘Low’ = disturbance categories 1-4; ‘Moderate’ = disturbance categories 5-7; and ‘High’ = disturbance categories 8 and 9; please note, these groupings are not representative of thresholds, they were used for comparative interpretations of disturbance outputs only. Disturbance groups from 2020 were selected as the focus of comparison of disturbance within and outside the OSPAR MPA Network to avoid any variations caused by increases on MPA designations. However, an exploratory analysis of trends in the distribution of disturbance between 2009 and 2020 was conducted in areas where BH3 is an agreed Common Indicator, to assess changes in annual disturbance levels within and outside the MPAs as designated in 2021, irrespective of any difference in MPA extent or designation type prior to 2021.

Results

Proportion of OSPAR MPA Network in BH3a Common Indicator Areas

An assessment of disturbance within MPAs was undertaken using data available from the OSPAR MPA Network Shapefile (OSPAR, 2021b). To identify the proportion of the MPA Network that had the most relevance to an assessment of seafloor disturbance, the Shapefile was refined to indicate the total area within MPAs with habitat features. Areas of the MPA Network where habitat data were not available were subsequently categorised as areas where only species features were present, or areas where no feature metadata was submitted to OSPAR.

In total, the OSPAR MPA Network (as of July 2021) covered 16.41% of the total area where BH3a was assessed as a Common Indicator in the OSPAR QSR 2023 (Table 1 and Figure 2). The majority of the assessed area within MPAs was in sites designated for habitat features, accounting for 12.51% of the total area where BH3a is a Common Indicator (hereafter referred to as ‘Common Indicator area’). MPAs with species features alone accounted for 3.72% of the Common Indicator area. In contrast, 0.18% of the Common Indicator area occurred in MPAs that did not have feature data available at the time of assessment; please note, not all nationally designated features were submitted to the OSPAR MPA database. The remaining 83.59% of the Common Indicator area was outside the extent of the OSPAR MPA Network.

Table 1 Percentage of the total area assessed by BH3a as a Common Indicator in the OSPAR QSR 2023 in the OSPAR MPA Network, as of July 2021.

Category	Percentage of Total Common Indicator Area
OSPAR MPAs With Habitat Features Submitted	12.51%

OSPAR MPAs With Species Features Only Submitted	3.72%
OSPAR MPAs With No Features Submitted	0.18%
Area Outside OSPAR MPAs	83.59%

Within individual assessment units, the percentage of the total area covered by the OSPAR MPA Network varied (Figure 3). Faroe Shetland Waters was the only assessment unit where MPAs were not present. Where MPAs were present, the total MPA coverage within assessment units ranged from ~ 0.23% in the South Iberian Atlantic, to 38.48% in the Gulf of Cadiz. Among assessment units, the area of the MPA Network with habitat features was predominantly greater than the area solely designated for species features, or where no features were submitted to OSPAR. However, exceptions were observed in the Kattegat and the Gulf of Cadiz, where the area in MPAs with species features alone was greater than the area with habitat features. Furthermore, areas within MPAs with no features submitted to OSPAR covered small percentages of the Norwegian Trench (0.38%), the Northern Celtic Sea (0.37%), and the Southern Celtic Sea (0.48%).

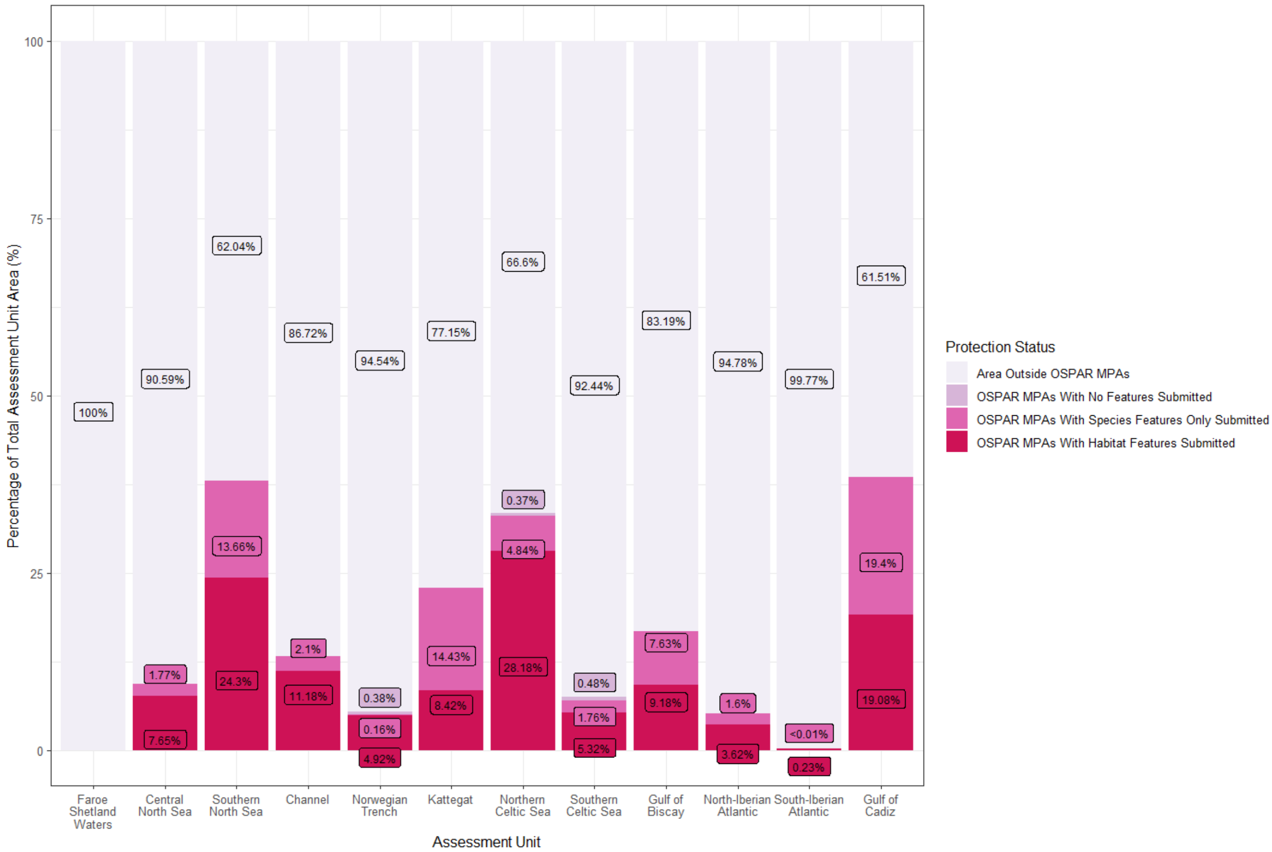

Figure 3 Percentage of the total area of Common Indicator assessment units covered by the OSPAR MPA Network as of July 2021.

Disturbance within and outside the OSPAR MPA Network, across BH3a Common Indicator Assessment Units in 2020

Across the total Common Indicator area, disturbance from bottom-contact fisheries covered a greater percentage of the area outside the OSPAR MPA Network than areas designated as MPAs in 2020 (Figure 4 and Figure 5). Outside MPAs, 56.93% of the area had 'Zero' disturbance, whereas within MPAs, 62.31% of the area had 'Zero' disturbance. Furthermore, ‘High’ and ‘Moderate’ disturbance groups also covered greater percentages of the area outside MPAs (9.27% and 16.6%, respectively), than within MPAs (5.13% and 13.7% respectively). In contrast, ‘Low’ disturbance covered a smaller percentage of the area outside MPAs (16.6%), than the area within MPAs (18.34%). However, these results represented disturbance within the total MPA area across Common Indicator assessment units and were irrespective of the different types of MPA features present within the network.

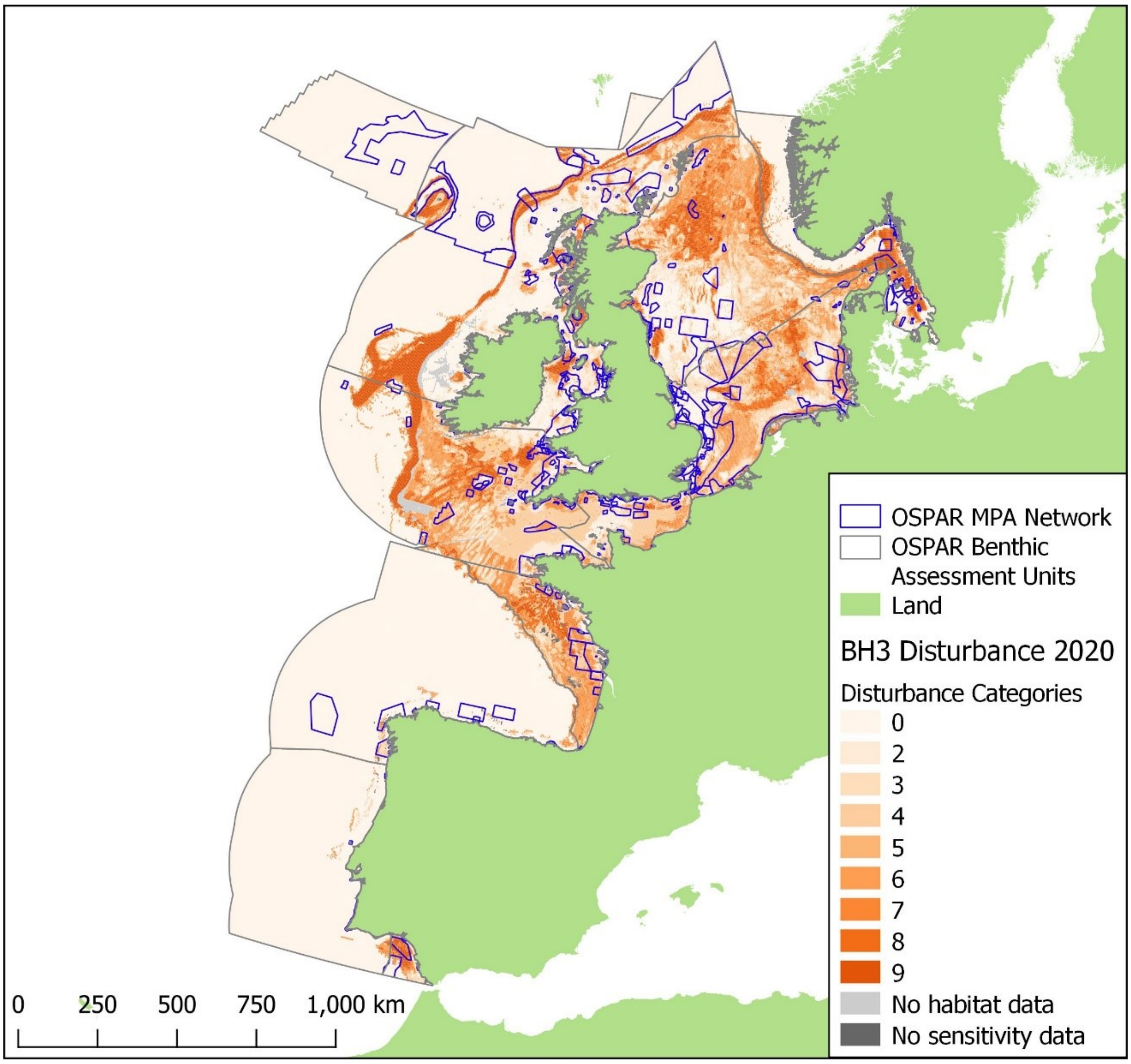

Figure 4: Spatial distribution of disturbance using VMS abrasion pressure data from 2020, with the OSPAR MPA Network overlaid. Disturbance categories ranged from “0” (0 SAR values or no reported VMS data), to “9” (most disturbed). In some instances, disturbance could not be assessed due to i) no habitat data, or ii) no sensitivity assessments for underlying habitat.

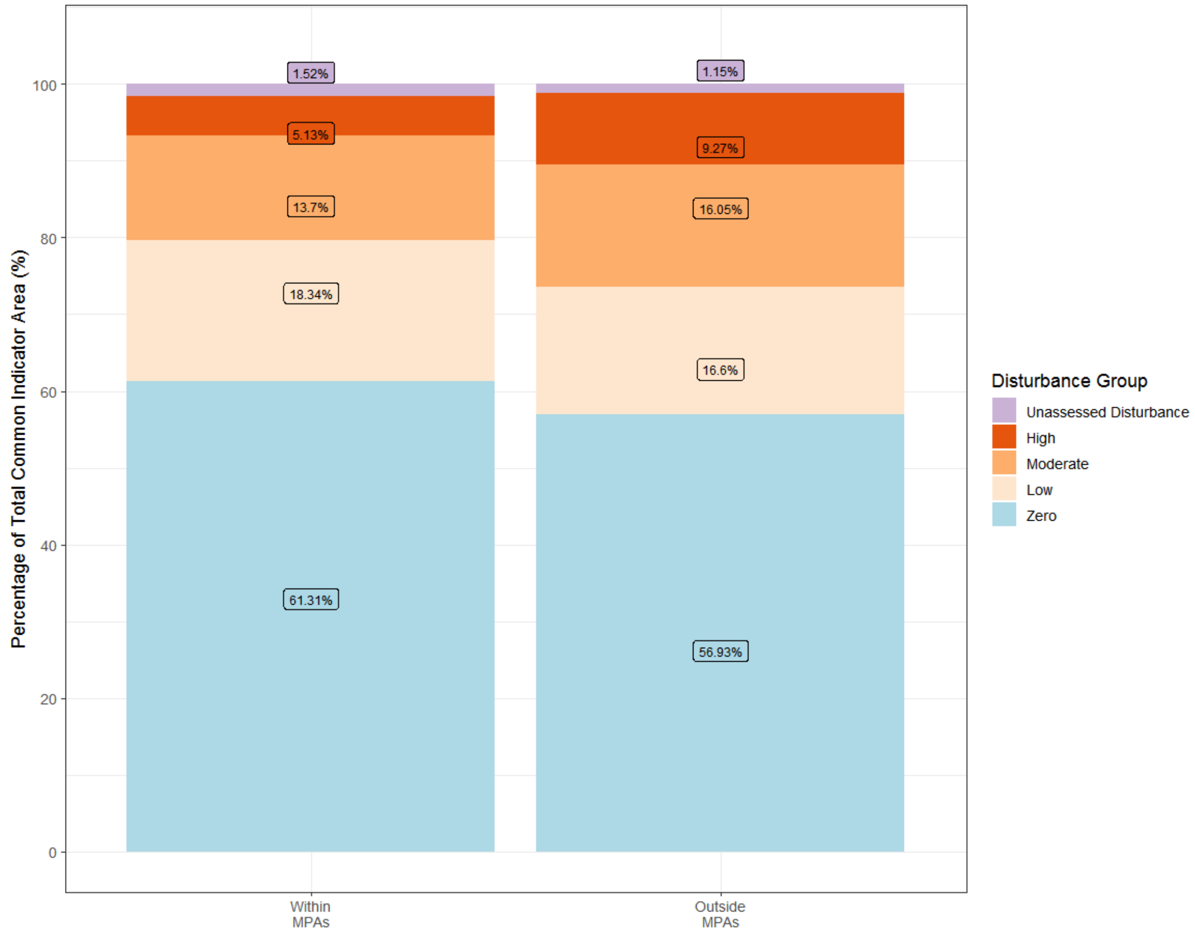

Figure 5: Percentage of the total Common Indicator area within and outside the OSPAR MPA Network (as of July 2021) in the following disturbance groups in 2020: 'Zero' = disturbance category 0; 'Low' = disturbance categories 1-4; 'Moderate' = disturbance categories 5-7; 'High' = disturbance categories 8 and 9; 'Unassessed Disturbance' = area where fishing pressure was present but disturbance could not be assessed due to i) no habitat data, or ii) no sensitivity assessments for underlying habitat.

When comparing disturbance from bottom-contact fisheries across areas of the OSPAR MPA Network with different designated features, the greatest percentage of area with disturbance was found in MPAs with species features alone (Figure 6). 'Zero' disturbance covered 36.91% of the area with species features alone, leaving over half of the remaining area (63.09%) in varying levels of disturbance (Low: 33.44%, Moderate:19.35%, High: 8.36%). In contrast, over half of the respective areas within MPAs with habitat features (68.34%) and MPAs with no features submitted (77.72%) had 'Zero' disturbance.

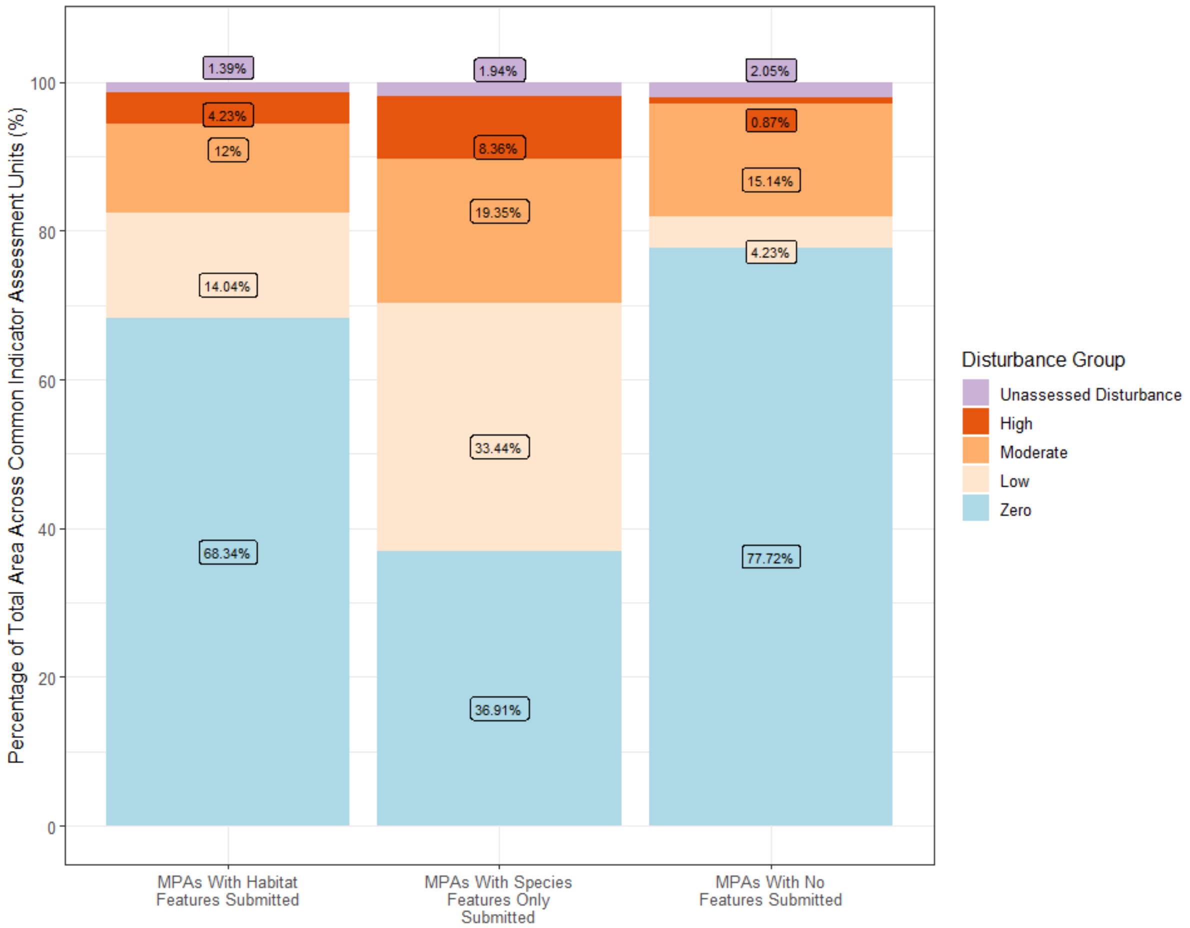

Figure 6: Percentage of the total area within OSPAR MPAs (as of July 2021) with different features across Common Indicator assessment units in the following disturbance groups in 2020: 'Zero' = disturbance category 0; 'Low' = disturbance categories 1-4; 'Moderate' = disturbance categories 5-7; 'High' = disturbance categories 8 and 9; 'Unassessed Disturbance' = area where fishing pressure was present but disturbance could not be assessed due to i) no habitat data, or ii) no sensitivity assessments for underlying habitat.

Statistics within and outside the OSPAR MPA Network per BH3a Assessment Units

Among the assessment units, it was generally observed that a larger proportion of the area outside the OSPAR MPA Network experienced disturbance from bottom-contact fisheries. (Figure 7). Three exceptions were observed in the Norwegian Trench, Southern Celtic Sea, and North-Iberian Atlantic, where disturbance covered a greater percentage of the area within MPAs, rather than outside of MPAs. Furthermore, instances of 'High' and 'Moderate' disturbance were most prevalent in areas outside of MPAs among most assessment units. In contrast, 'Low' disturbance was more prevalent within MPAs among most assessment units.

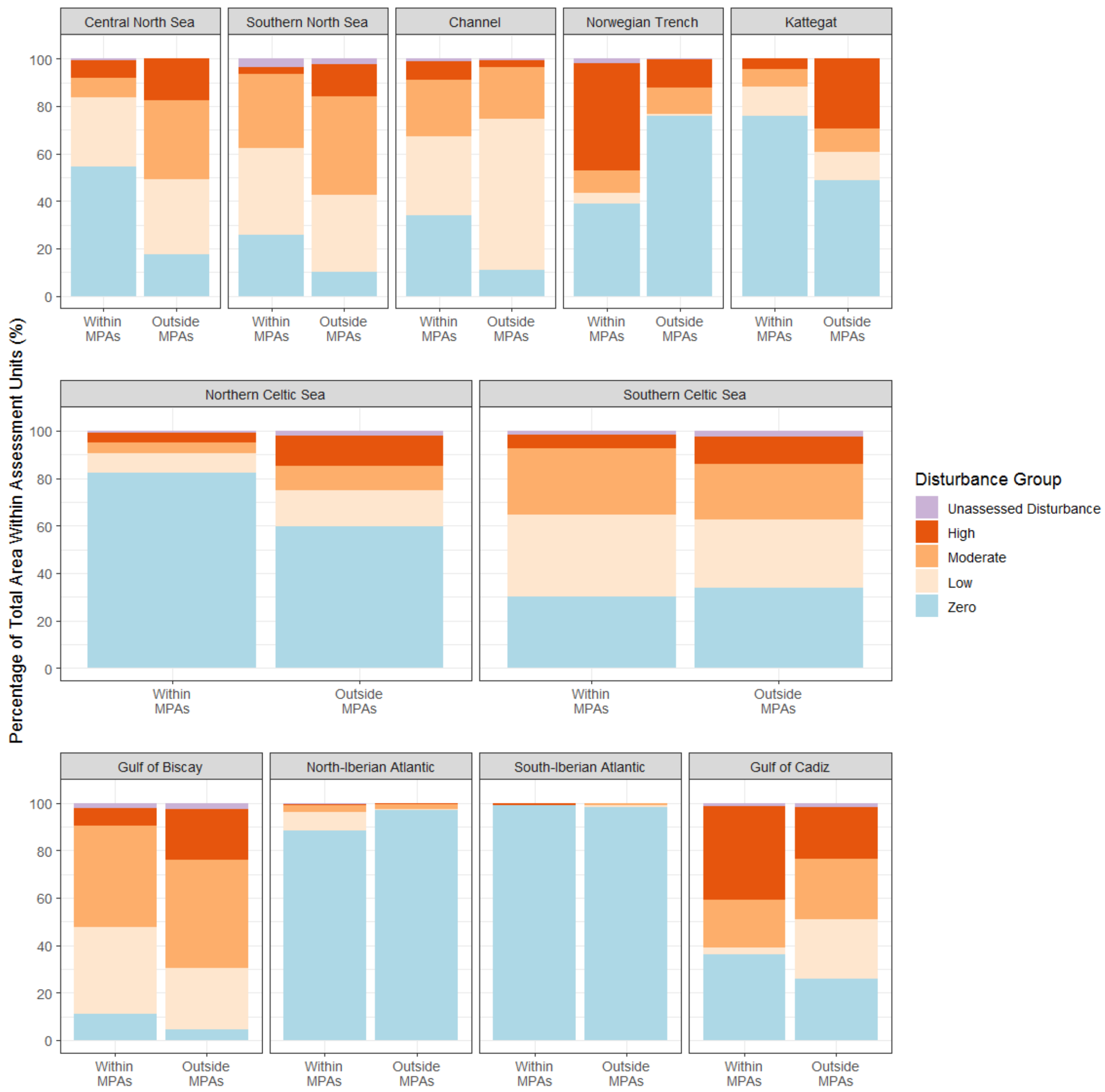

Figure 7: Percentage of the total assessment unit area within and outside OSPAR MPAs (as of July 2021) in the following disturbance groups in 2020: 'Zero' = disturbance category 0; 'Low' = disturbance categories 1-4; 'Moderate' = disturbance categories 5-7; 'High' = disturbance categories 8 and 9; 'Unassessed Disturbance' = area where fishing pressure was present but disturbance could not be assessed due to i) no habitat data, or ii) no sensitivity assessments for underlying habitat. Individual assessment unit plots are grouped by OSPAR Region and are displayed in the following order from top to bottom: Region II, Region III, Region IV. Note that Faroe Shetland Waters is not shown due the absence of OSPAR MPAs in the assessment unit.

The prevalence of disturbance in areas with different protected features varied among assessment units (Figure 8). Disturbance covered a greater percentage of the area within MPAs with species features alone in all assessment units in Region IV and in the Northern Celtic Sea. Within these assessment units, the coverage of disturbance within the area of MPAs with species features alone ranged from 35% in the North-Iberian Atlantic to 100% in the South-Iberian Atlantic. However, in all assessment units in Region II and the Southern Celtic Sea, disturbance covered a greater percentage of the area within MPAs with habitat features. Within these assessment units, the coverage of disturbance within the area of MPAs with habitat features ranged from 44% in the Kattegat to 73% of the Southern Celtic Sea.

Additionally, splitting the assessment unit area within OSPAR MPAs by the different types of features indicated that notably large proportions of these areas were in disturbance groups representative of higher disturbance categories (Figure 8). In the Norwegian Trench, over 50% of the area within MPAs with habitat features had 'High' disturbance alone. 'High' disturbance also covered over 50% of the area of the South-Iberian Atlantic and the Gulf of Cadiz within MPAs with species features alone. Furthermore, a combination of both 'High' and 'Moderate' disturbance covered over 50% of the area within MPAs with species features alone in the Gulf of Biscay.

Figure 8: Percentage of the total area within OSPAR MPAs (as of July 2021) with different features within assessment units in the following disturbance groups in 2020: 'Zero' = disturbance category 0; 'Low' = disturbance categories 1-4; 'Moderate' = disturbance categories 5-7; 'High' = disturbance categories 8 and 9; 'Unassessed Disturbance' = area where fishing pressure was present but disturbance could not be assessed due to i) no habitat data, or ii) no sensitivity assessments for underlying habitat. Individual assessment unit plots are grouped by OSPAR Region and are displayed in the following order from top to bottom: Region II, Region III, Region IV. Note that Faroe Shetland Waters is not shown due the absence of OSPAR MPAs in the assessment unit.

Common indicator area: Comparison of Disturbance Within and Outside the OSPAR MPA Network

Across the Common Indicator area, comparing disturbance levels between 2009 and 2020 from bottom-contact fisheries both inside and outside the OSPAR MPA Network (as of July 2021), indicated that the highest proportion of disturbance area had transitioned from within MPAs in 2009 to outside MPAs in 2020 (Figure 9). In 2009 53.88% of the area within MPAs had ‘Zero’ disturbance, whereas outside MPAs, 55.36% of the area had ‘Zero’ disturbance. In 2020, the area under ‘Zero’ disturbance increased both within and outside MPAs, indicative of an overall decrease in the extent of disturbance from bottom-contact fisheries across the Common Indicator area. However, the increase in ‘Zero’ disturbance was proportionally larger within MPAs. An analysis of disturbance throughout the timeseries indicated that the overall increase in ‘Zero’ disturbance was a result of consistent trends throughout time in both areas (Figure 10).

Furthermore, both within and outside the OSPAR MPA Network (as of July 2021), the extent of ‘High’ and ‘Moderate’ disturbance decreased, and the extent of ‘Low’ disturbance increased between 2009 and 2020 (Figure 9). However, these changes were once again proportionally larger within MPAs. In 2009, an additional 2.51% and 5.92% of the area within MPAs had ‘High’ and ‘Moderate’ disturbance respectively, and outside MPAs an additional 1.58% and 0.89% of the area had ‘High’ and ‘Moderate’ disturbance respectively. In 2020, ‘Low’ disturbance covered an additional 1.46% of the area within MPAs, and an additional 1.25% of the area outside MPAs respectively.

Analysis of disturbance throughout the time series showed varying trends among the different assessed disturbance groups (‘High’, ‘Moderate’, and ‘Low’) within and outside the OSPAR MPA Network as of July 2021 (Figure 10). Within MPAs, the decrease in ‘High’ and ‘Moderate’ disturbance was a relatively consistent trend throughout time. However, despite the overall increase in ‘Low’ disturbance within MPAs, this disturbance group fluctuated throughout the time series and no clear trend was visible. Furthermore, outside MPAs, due to small observed changes over time, no consistent trends were observed in the proportions of ‘High’, ‘Moderate’ and ‘Low’ disturbance throughout the time series.

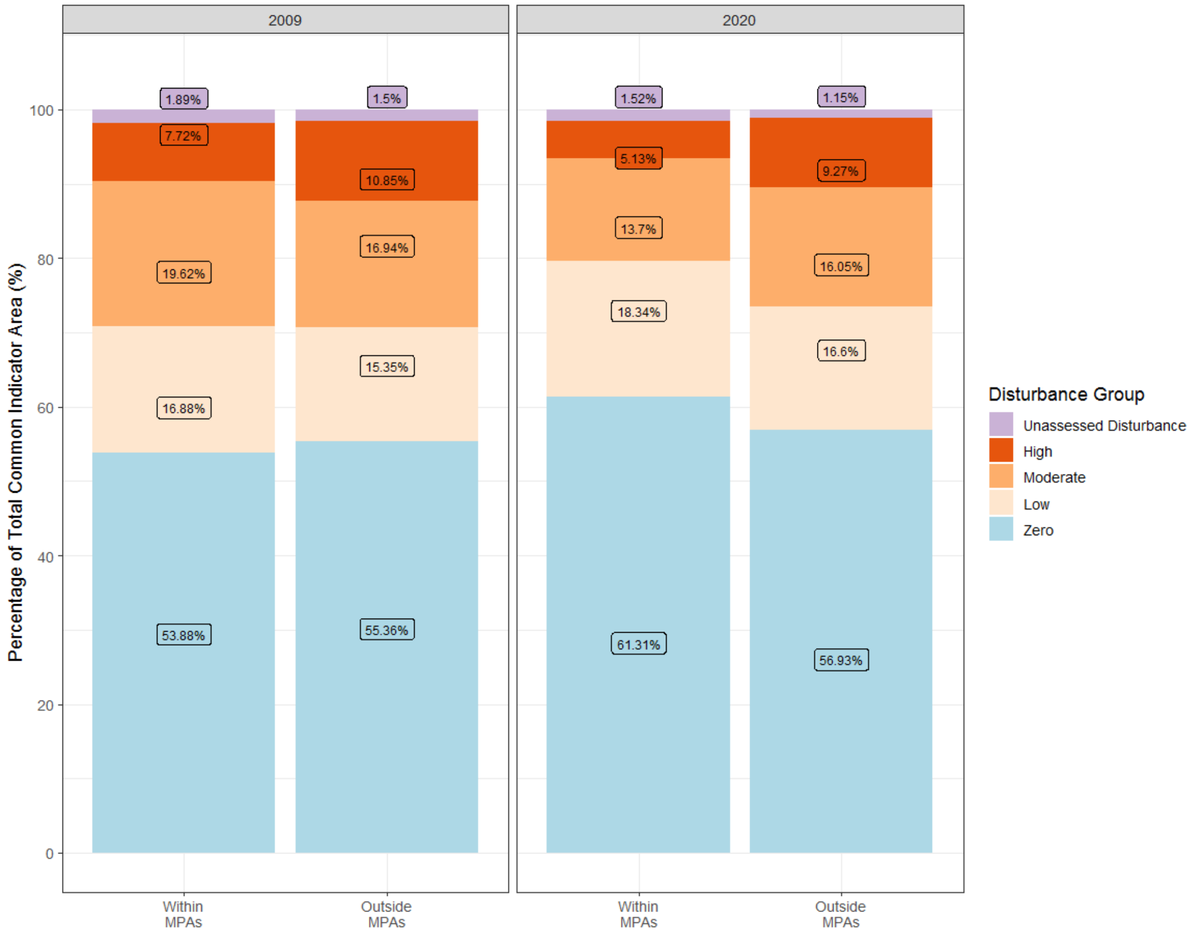

Figure 9: Comparison of the percentage of the total Common Indicator area within and outside the OSPAR MPA Network (as of July 2021) in the following disturbance groups in 2009 and 2020: 'Zero' = disturbance category 0; 'Low' = disturbance categories 1-4; 'Moderate' = disturbance categories 5-7; 'High' = disturbance categories 8 and 9; 'Unassessed Disturbance' = area where fishing pressure was present but disturbance could not be assessed due to i) no habitat data, or ii) no sensitivity assessments for underlying habitat.

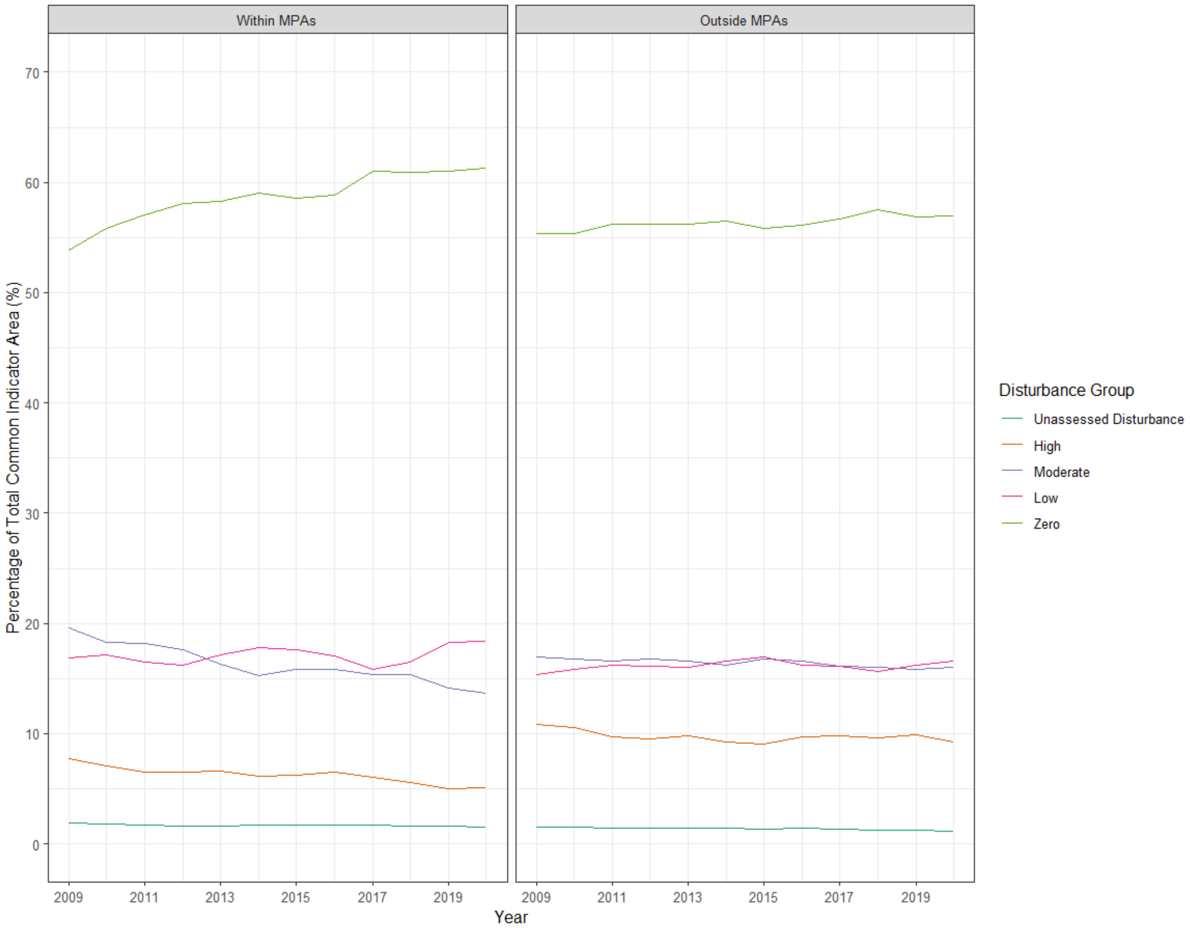

Figure 10: Trends in the percentage of the total Common Indicator area within and outside OSPAR MPAs (as of July 2021) in the following disturbance groups between 2009 and 2020: 'Zero' = disturbance category 0; 'Low' = disturbance categories 1-4; 'Moderate' = disturbance categories 5-7; 'High' = disturbance categories 8 and 9; 'Unassessed Disturbance' = area where fishing pressure was present but disturbance could not be assessed due to i) no habitat data, or ii) no sensitivity assessments for underlying habitat.

A direct comparison of disturbance from bottom-contact fisheries within areas of the OSPAR MPA Network (as of July 2021) with different features across the Common Indicator area between 2009 and 2020 indicated that the proportion of area under 'Zero' disturbance had increased across all feature types (Figure 11). Proportionally, the greatest increase in 'Zero' disturbance was observed in MPAs with species features only, where an additional 10.57% of the area had 'Zero' disturbance in 2020. This was followed by an additional 6.56% of the area in MPAs with no designated features and an additional 6.5% of the area in MPAs that included habitat features. Furthermore, in MPAs with habitat or species features the proportion of 'Zero' disturbance increased throughout most of the time series between 2009 and 2020 (Figure 12). However, it should be noted that between 2017 and 2020, the proportion of 'Zero' disturbance decreased slightly in MPAs with habitat features. Furthermore, despite the overall increase in 'Zero' disturbance in MPAs with no designated feature information, 'Zero' disturbance fluctuated throughout the time series in these areas and showed no clear trends.

Changes in the prevalence of the remaining assessed disturbance groups ('High', 'Moderate' and 'Low') varied across areas with different features between 2009 and 2020 (Figure 11). Within MPAs with habitat or species features the proportion of 'High' and 'Moderate' disturbance decreased, and the proportion of 'Low' disturbance increased. However, within MPAs with no designated features, the proportion of 'High' disturbance decreased, and the proportion of 'Moderate' and 'Low' disturbance increased.

Analysis of disturbance throughout the time series showed varying trends among the different assessed disturbance groups ('High', 'Moderate', and 'Low') within areas of the OSPAR MPA Network with different features (Figure 12). Within MPAs with habitat or species features the decrease in 'High' and 'Moderate' disturbance was a relatively consistent trend throughout time. However, despite the overall increase in 'Low' disturbance within MPAs with habitat or species features, this disturbance group fluctuated throughout the time series and no clear trend was visible. Furthermore, in MPAs with no designated features, the proportions of 'High', 'Moderate' and 'Low' disturbance fluctuated throughout the timeseries, and no clear trends were visible. However, the area of MPAs with no designated features covered a relatively small proportion of the Common Indicator area (Table 1). Consequently, any changes in disturbance resulted in proportionally larger fluctuations in these areas.

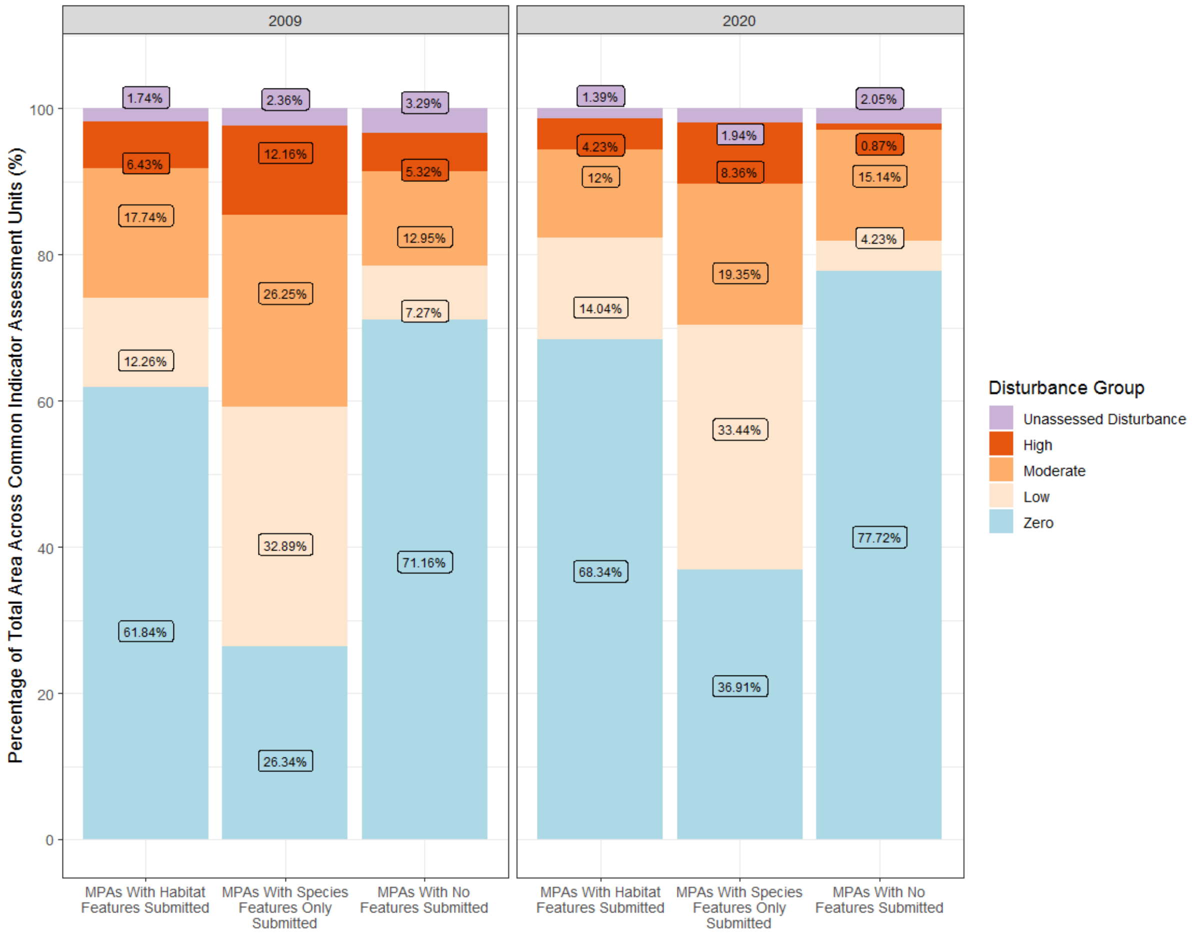

Figure 11: Percentage of the total area within OSPAR MPAs (as of July 2021) with different features across Common Indicator assessment units in the following disturbance groups in 2009 and 2020: 'Zero' = disturbance category 0; 'Low' = disturbance categories 1-4; 'Moderate' = disturbance categories 5-7; 'High' = disturbance categories 8 and 9; 'Unassessed Disturbance' = area where fishing pressure was present but disturbance could not be assessed due to i) no habitat data, or ii) no sensitivity assessments for underlying habitat.

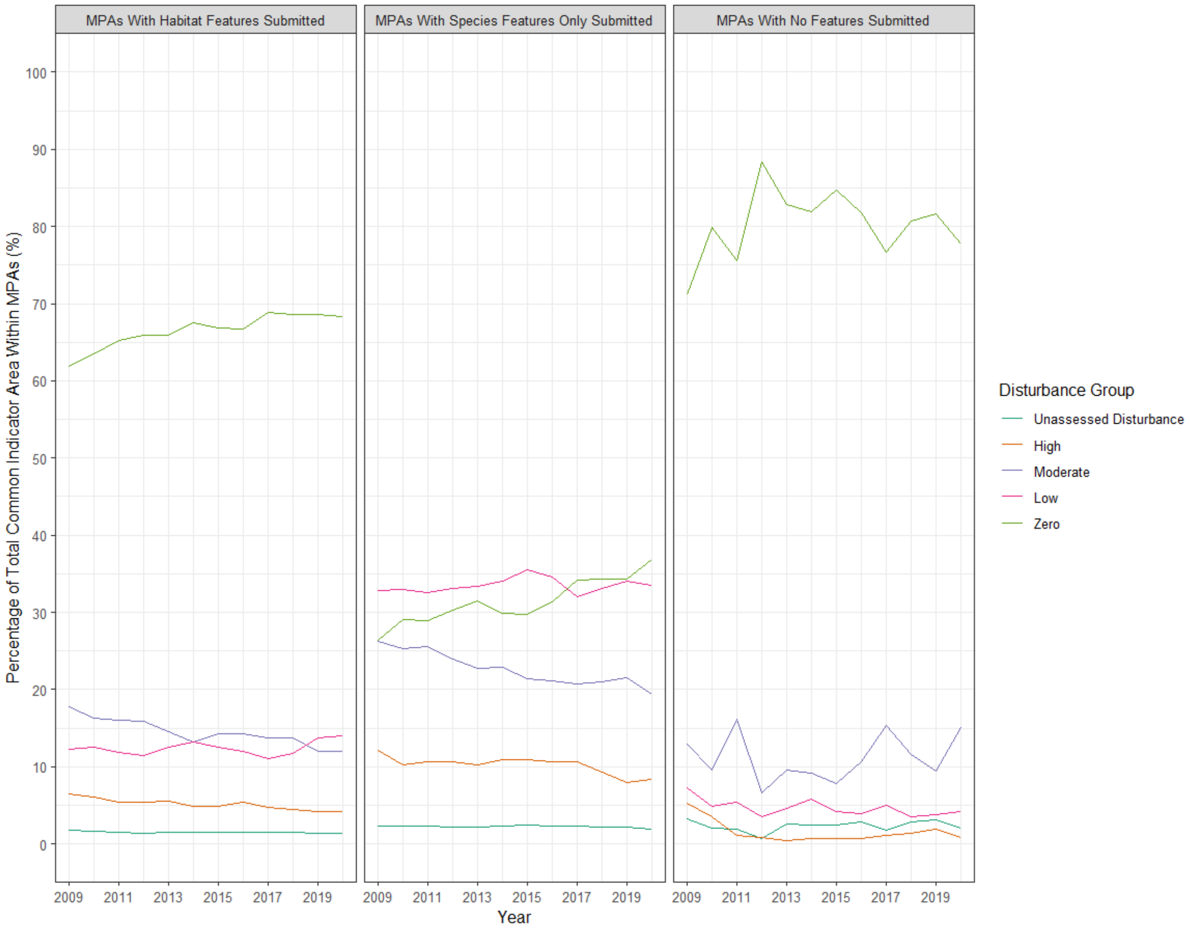

Figure 12: Trends in the percentage of the total Common Indicator area within areas of the OSPAR MPAs Network (as of July 2021) with different features in the following disturbance groups between 2009 and 2020: 'Zero' = disturbance category 0; 'Low' = disturbance categories 1-4; 'Moderate' = disturbance categories 5-7; 'High' = disturbance categories 8 and 9; 'Unassessed Disturbance' = area where fishing pressure was present but disturbance could not be assessed due to i) no habitat data, or ii) no sensitivity assessments for underlying habitat.

Candidate Indicator Area: Distribution of the OSPAR MPA Network

The OSPAR MPA Network (as of July 2021) covered 11.63% of the area where BH3a was assessed as a Candidate Indicator in the OSPAR QSR 2023 (Table 2). The Candidate Indicator assessment area only included the Atlantic Projection assessment unit, where the area covered by the MPA Network was concentrated in the centre of the assessment unit (Figure 2). Furthermore, all OSPAR MPAs present in the Atlantic Projection contained habitat features. Therefore, subsequent analyses of disturbance within MPAs were not categorised by features in this assessment unit.

Table 2: Percentage of the total area assessed by BH3a as a Candidate Indicator (Atlantic Projection assessment unit) in the OSPAR QSR 2023 in the OSPAR MPA Network, as of July 2021.

Category	Percentage of Total Common Indicator Assessment Area
OSPAR MPAs With Habitat Features Submitted	11.63%
Area Outside OSPAR MPAs	88.37%

Candidate Indicator Area: Disturbance Within and Outside the OSPAR MPA Network

In the Atlantic Projection assessment unit, disturbance covered a greater percentage of the area outside the OSPAR MPA Network than within the MPA Network (Figure 13). However, the difference in disturbance within and outside the MPA network was small; 99.03% of the area outside MPAs and 99.49% of the area within MPAs had 'Zero' disturbance respectively. Furthermore, small differences in the percentage of the area within and outside the OSPAR MPA network in the remaining disturbance groups were observed. 'High' disturbance covered 0.52% of the area outside MPAs, whereas 'High' disturbance was not observed within MPAs. Additionally, 'Moderate' disturbance covered a greater percentage of the area outside MPAs (0.35%) than within MPAs (0.04%). In contrast, 'Low' disturbance covered a greater percentage of the area within MPAs (0.13%), than outside MPAs (0.09%). These results were representative of MPAs with habitat features, and due to the absence of MPAs without habitat features, no further comparison could be done between MPAs with different types of features within the Atlantic Projection.

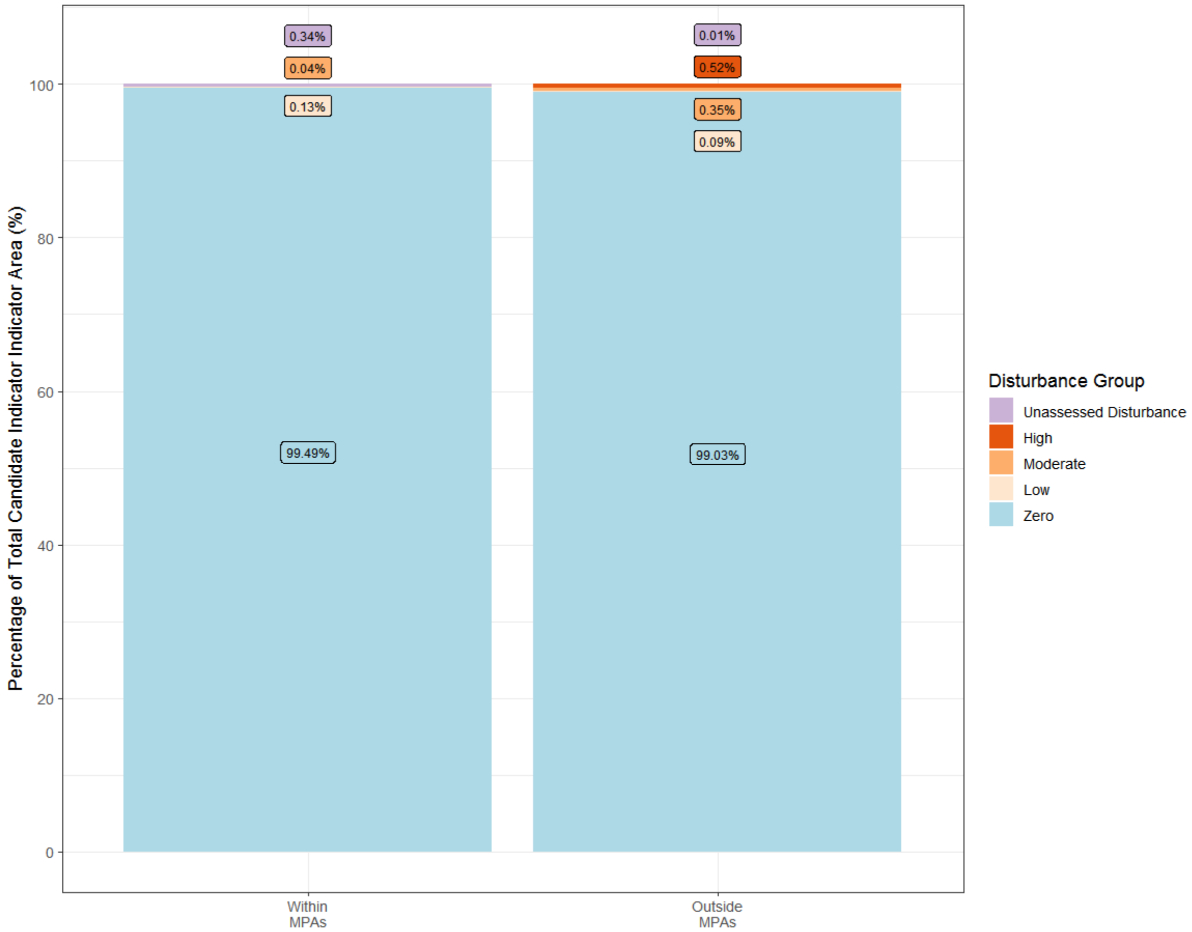

Figure 13: Percentage of the total Candidate Indicator area (Atlantic Projection assessment unit) within and outside OSPAR MPAs in the following disturbance groups: 'Zero' = disturbance category 0; 'Low' = disturbance categories 1-4; 'Moderate' = disturbance categories 5-7; 'High' = disturbance categories 8 and 9; 'Unassessed Disturbance' = area where fishing pressure was present but disturbance could not be assessed due to i) no habitat data, or ii) no sensitivity assessments for underlying habitat.

Discussion

This task demonstrated the use of the Extent of Physical Disturbance to Benthic Habitats indicator (BH3a) QSR 2023 results, in combination with the spatial location of OSPAR MPAs, to assess differences in disturbance within and outside the OSPAR MPA Network. By employing a range of spatial analysis techniques in GIS and R statistical software, the study successfully identified spatial and temporal variations in the distribution and intensity of disturbance to benthic habitats within and outside the OSPAR MPA Network (as of July 2021) between 2009 and 2020.

The analysis found that in 2020, disturbance from bottom-contact fisheries covered a slightly smaller proportion of the area within the OSPAR MPA Network than outside MPAs. Furthermore, ‘High’ and ‘Moderate’ disturbance groups were more prevalent outside MPAs and ‘Low’ disturbance was more prevalent within MPAs. These variations were further assessed in MPAs with habitat features, where the proportion of overall disturbance from bottom-contact fisheries and the proportion of individual disturbance groups (‘High’, ‘Moderate’ and ‘Low’) were less prevalent than within MPAs with species features alone. These results indicated that MPAs, and specifically areas protected for benthic features, had a lesser extent and intensity of disturbance from bottom-contact fisheries than areas outside MPAs, as well as areas protected for typically transient species. However, due to data paucity (low resolution fishing data and lack of MPA management information), exact reasons for these differences could not be inferred at the time of assessment. Furthermore, these results were not consistent across individual assessment units.

This analysis highlighted the differences of disturbance severity within MPAs across different assessment units. For example, in the Norwegian Trench, Southern Celtic Sea, and North-Iberian Atlantic, disturbance covered a greater percentage of the area within MPAs, than outside of MPAs. Furthermore, the analysis identified assessment units where the proportion of ‘High’ disturbance was greater within than outside MPAs, notably in the Norwegian Trench and the Gulf of Cadiz.

The exploratory analysis of trends over time within and outside the OSPAR MPA Network (as of July 2021) indicated changes in the extent of disturbance from bottom-contact fisheries within and outside MPAs between 2009 and 2020. The assessment showed an overall decrease in the extent and intensity of disturbance with proportionally more pronounced decreases observed within MPAs, particularly those with species features alone. Furthermore, the aforementioned changes appeared to be driven by consistent trends throughout time within the MPA Network and, despite the potential disruption to fishing activity in 2020 from the COVID-19 pandemic, disturbance from 2020 aligned with the trends observed in previous years. However, it should be noted that investigating changes within individual assessment units and testing for statistically significant changes was beyond the scope of this study.

The variations of disturbance within and outside MPAs should be considered in the wider biogeographic context of each assessment unit and the distribution of designated areas. Lower percentages of disturbance within MPAs could potentially relate to the designation of features or areas not suitable for bottom-contact fishing activities, such as rocky or stony reef habitats or areas where the activity is prohibited, i.e., in depths greater than 800 m (European Union, 2016). For example, the Southern Celtic Sea and North-Iberian Atlantic assessment units had a greater proportion of disturbance within MPAs, however MPAs were predominantly located in continental shelf waters where bottom-contact fisheries are more prevalent. In contrast, the Northern Celtic Sea has substantial MPAs beyond continental waters and subsequently lower proportions of disturbance within MPAs.

Whilst the current assessment highlighted the possibility that disturbance to benthic habitats was reduced in areas designated as MPAs, several additional factors could have influenced the results beyond the scope of any implemented MPA management measures. Potential drivers behind the differences could have included changes in trends in fishing activity since 2009. In the UK alone, fishing effort by vessels over 10 m has decreased by around 43% since 2003 (approximately 25% between 2009 and 2020; MMO, 2022), mostly driven by a reduction in the demersal trawl and seine segment. Whilst some of these reductions in fishing effort can be attributed to fisheries management measures, for example the Cod Recovery Zone and the Sole Recovery Zone (MMO, 2022), they are not necessarily specific to the implementation of MPA management measures. Therefore, all results should be considered as an initial evaluation and exploratory work on the use of indicators to evaluate spatial protection measures; reductions in disturbance could not be specifically attributed to the effectiveness of management measures within MPAs.

This study has demonstrated that indicator led assessments, such as BH3a, could be useful tools to evaluate differences in potential disturbance to benthic habitats associated with bottom-contact fisheries within and outside MPAs. However, a full assessment, including drivers of observed differences, could not be completed due to limitations associated with available data. For example, information on MPA-specific management measures was limited, and where available from other sources, data were often complex and location specific (e.g., voluntary measures, use of the existing planning and licensing frameworks, byelaws, and orders). Nevertheless, exploratory findings from this study could be used to help guide future assessments, should the required data on MPA features and associated management measures become more readily accessible.

Concluding remarks and recommendations for next steps for assessing the effectiveness of management measures

When analysing data from the OSPAR MPA Network, key knowledge gaps were identified that hindered the delivery of a comprehensive assessment of management measure effectiveness. Drawing from the information synthesised within this study, the following recommendations have been developed to help facilitate future work and improve overall understanding on the effectiveness of MPA-related management measures relevant to fishing impacts.

The BH3a assessment for the OSPAR QSR 2023 used ICES VMS layers to quantify fishing pressure throughout the OSPAR Maritime Area (Matear, *et al.,* 2023). Pressure data available at the time of this study were missing fleet data from Portugal, Iceland and Norway and VMS data was unavailable for vessels less than 12 m between 2012 and 2020, and vessels less than 15 m between 2009 and 2012 (ICES, 2021). Furthermore, due to a lack of detail available in c-square grid cells used (VMS data is published at a 0.05 x 0.05 decimal degree grid resolution), a low-resolution of VMS ping rates (2-hourly intervals) and assumed homogeneous distribution of fishing activity within a given grid cell, it was possible that fishing pressure was both over- and underestimated, in certain areas in this study. These factors are of particular relevance when assessing disturbance near or around MPA boundaries, as the resolution of fishing pressure data available does not necessarily allow for accurate determination of whether fishing activity occurred within or outside an MPA boundary. Higher resolution of VMS data, as well as future inclusion of Inshore Vessel Monitoring Systems (I-VMS) data would increase the confidence of assessments of disturbance within MPAs.

Additional limitations were associated with the habitat and sensitivity information available at the time of the BH3a assessment for the OSPAR QSR 2023. Habitat maps within MPAs in the United Kingdom were predominantly mapped at a Broadscale Habitat-level (EUNIS Level 3), which equated to the level of habitat classification commonly used in feature designations. Therefore, it was possible that areas outside of MPAs had more detailed habitat and sensitivity information (EUNIS Levels 4 to 6), resulting in more precautionary assessments within MPAs (Matear *et al.*, 2023). Moreover, habitat and species sensitivity information available at the time of assessment were predominantly derived from sensitivity assessments most relevant to northern European waters, which may have limited the accuracy of findings in wider areas. Please see the QSR 2023 BH3a assessment for a full analysis and critical discussion of input data available at the time of assessment (Matear *et al.*, 2023). Additionally, to maintain environmental protection, barriers can remain around the sensitive and confidential detailed locations of protected species or habitats.

Improved designated feature information for each MPA would enable more targeted assessments to ensure that benthic indicators are applied in areas where the protection of benthic habitats are a policy priority. A small proportion of MPAs within the OSPAR MPA Network had no features submitted by OSPAR Contracting Parties, which prevented a complete assessment of MPAs by designation type (habitat features or species features alone). Therefore, future work would benefit from a full list of protected features within all MPAs submitted to the OSPAR Network.

Data from the OSPAR MPA Network indicated that management measures were present within some MPAs (OSPAR, 2021c). However, information on the exact nature of these management measures, the extent to which they were implemented, and whether they had associated enforcement was not available. Therefore, a critical analysis beyond identifying MPA presence alone was not possible at the time of this assessment. Additionally, the assessment of MPAs was limited to those submitted for inclusion in the OSPAR MPA Network by individual Contracting Parties. Assessments found that the data reported to the Network did not fully encompass all areas where management measures for bottom-contacting fishing were implemented throughout the OSPAR Maritime Area (e.g., Swedish No Trawl Zone identified in the BH3a assessment) (Matear *et al.,* 2023).

Access to improved information on MPA-specific management measures could improve future assessments of the effectiveness of management measures within MPAs. Information specifically related to the types of measures agreed upon within MPAs would enhance understanding of the effect of management measures on the magnitude and distribution of physical disturbance within these designated sites. Key information could include details of fishing restrictions, and associated spatiotemporal constraints, such as where restrictions are in effect, and whether such measures are seasonal or annual (e.g., permanent closures to specific fishing gears). Furthermore, information such as spatial data on the location of implementation / enforcement action; monitoring data linked to assessment of impacts of introduced actions; whether conservation objectives have been successfully met; and if improvements following designation can be demonstrated could further improve understanding of the environmental responses to fishing disturbance within the MPA Network.

References

CBD (2020). Aichi Biodiversity Targets. Available online: https://www.cbd.int/sp/targets/ (Accessed: April 2023)

CBD (2021). A New Global Framework for Managing Nature Through 2030: First Detailed Draft Agreement Debuts. Available online: https://www.cbd.int/article/draft-1-global-biodiversity-framework (Accessed: April 2023)

Collie, J. S., Hall, S. J., Kaiser, M. J., and Poiner, I. R. (2001). A quantitative analysis of fishing impacts on shelf-sea benthos. *Journal of Animal Ecology,* 69(5): 785-798

Eigaard, O.R., Bastardie, F., Breen, M., Dinesen, G.E., Hintzen, N.T., Laffargue, P., Mortensen, L.O., Rasmus Nielsen, J., Nilsson, H.C., O'Neill, F.G., Polet, H., Reid, D.G., Sala, A., Sköld, M., Smith, C., Sørensen, T.K., Tully, O., Zengin, M., and Rijnsdorp, A.D. (2016). Estimating seabed pressure from demersal trawls, seines, and dredges based on gear design and dimensions. *ICES Journal of Marine Science*, 73(suppl_1): i27-i43

European Union, (2016). Regulation (EU) 2016/2336 of the European Parliament and of the Council of 14 December 2016 establishing specific conditions for fishing for deep-sea stocks in the North-East Atlantic and provisions for fishing in international waters of the North-East Atlantic and repealing Regulation (EC) No 2347/2002. *Official Journal of the European Union*, L 354, 1-43.

ESRI, (2012). ArcGIS Release 10.1. Redlands, CA.

Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., D'Agrosa, F., Bruno, J. F., Casey, K. S., Ebert, C., Fox, H. E., Fujita, R., Heinemann, D., Lenihan, H. S., Madin, E. M., Perry, M. T., Selig, E. R., Spalding, M., Steneck, R., and Watson, R. (2008). A Global Map of Human Impact on Marine Ecosystems. *Science*, 319:948-952.

Hennicke, J., Blanchard, S., Chaniotis, P., Cornick, L., Hauswirth, M., Schellekens, T., Vonk, S., and Werner, T. (2022). Report and assessment of the status of the OSPAR network of Marine Protected Areas in 2021. In: OSPAR, 2023: The 2023 Quality Status Report for the North-East Atlantic. OSPAR Commission, London. Available at: https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-ospar-network-marine-protected-areas/assessment-reports-mpa/mpa-2021

Hiddink, J.G., Jennings, S. Sciberras, M., Szostek, C.L., Highes, K.M., Ellis, N., Rijnsdorp, A. D., McConnaughey, R. A., Mazor, T., Hilbron, R., Collie, J.S., Pitcher, C.R., Amoroso, R.O., Parma, A.M., Suuronen, P., and Kaiser, M.J., (2017). Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. *PNAS.* 114(31): 8301-8306.

ICES (2021). OSPAR request on the production of spatial data layers of fishing intensity / pressure. *ICES Technical service.*

Kaiser, M. J., Clarke, K. R., Hinz, H., Austen, M. C. V., Somerfield, P. J., and Karakassis, I. (2006). Global analysis of response and recovery of benthic biota to fishing. *Marine Ecology Progress Series,* 311: 1-14.

Marine Scotland, (2020). Marine Protected Area (MPA): West of Scotland Deep Sea Reserve Order 2020. *Scottish Ministerial Order.*

Matear, L., Vina-Herbon, C., Woodcock, K.A., Duncombe-Smith, S.W., Smith, A.P., Schmitt, P., Kreutle, A., Marra, S., Curtis, E.J., & Baigent, H.N. (2023). Extent of Physical

Disturbance to Benthic Habitats (BH3a): Fisheries. In: OSPAR, 2023: The 2023 Quality Status Report for the Northeast Atlantic. OSPAR Commission, London. OSPAR Benthic Habitats Expert Group, Intersessional Correspondence Group on the Coordination of Biodiversity Assessment and Monitoring, OSPAR Biodiversity Committee.

Marine Management Organisation, (2022). UK Sea Fisheries Statistics Report 2021. Available online: https://www.gov.uk/government/statistics/uk-sea-fisheries-annual-statistics-report-2021 (Accessed: May 2023)

OSPAR. (2008). OSPAR List of Threatened and/or Declining Species and Habitats (OSPAR Agreement 2008-06). *OSPAR Commission.*

OSPAR. (2010). Quality Status Report 2010. *OSPAR Commission*. *London.*

OSPAR. (2017). Intermediate Assessment. *OSPAR Commission*. *London.*

OSPAR. (2020). Report of the meeting of ICG-MPA 2020. *OSPAR Commission.*

OSPAR. (2021a). Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2030 (OSPAR Agreement 2021-01: North-East Atlantic Environment Strategy (replacing Agreement 2010-03). *OSPAR Commission.*

OSPAR. (2021b). OSPAR Marine Protected Areas Network. Available online: https://odims.ospar.org/en/submissions/ospar_mpa_2021_07/ (Accessed: April 2023)

OSPAR. (2021c). OSPAR MPA database. Available online: https://mpa.ospar.org/home-ospar (Accessed: April 2023)

OSPAR. (2023). Marine Protected Areas. Available online: https://www.ospar.org/work-areas/bdc/marine-protected-areas (Accessed: April 2023).

Pebesma, E. (2018). Simple Features for R: Standardized Support for Spatial Vector Data. *The R Journal 10 (1)*, 439-446, https://doi.org/10.32614/RJ-2018-009

QGIS Development Team (2021). QGIS Geographic Information System. Open Source Geospatial Foundation. http://qgis.org

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Van Denderen, P. D., Bolam, S. G., Hiddink, J. G., Jennings, S., Kenny, A., Rijnsdorp, A. D., and van Kooten, T. (2015). Similar effects of bottom trawling and natural disturbance on composition and function of benthic communities across habitats. *Marine Ecology Progress Series,* 341: 31-43.

Wells, S., Ray, G. C., Gjerde, K. M., White, A. T., Muthiga, N., Creel, J. E. B., Causey, B. D., McCormick-Ray, J., Salm, R., Gubbay, S., Keller, G., and Reti, J. (2016). Building the future of MPAs – lessons from history. *Aquatic Conservation Marine and Freshwater Ecosystems,* 26(S2): 101-125.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L.D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T.L., Miller, E., Bache, S.M., Müller, K., Ooms, J., Robinson, D., Seidel, D.P., Spinu, V., Takahashi, K., Vaughan, D., Wilke, C., Woo, K., Yutani, H. (2019). "Welcome to the tidyverse." *Journal of Open Source Software*, 4(43), 1686. doi:10.21105/joss.01686.