Ecological Indicators 147 (2023) 109973

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

A data-driven method for identifying conservation-relevant benthic habitats

Rebecca E. Ross [a,*], Genoveva Gonzalez-Mirelis [a], Gunnstein Bakke [b], Margaret F.J. Dolan [c], Pål Buhl-Mortensen [a]

[a] *Institute of Marine Research, P.O. Box 1870 Nordnes, 5817 Bergen, Norway*
[b] *Directorate of Fisheries, P.O. Box 185 Sentrum, 5804 Bergen, Norway*
[c] *Geological Survey of Norway (NGU), P.O. Box 6315 Torgarden, 7491 Trondheim, Norway*

ARTICLE INFO

Keywords:
VME
EBSA
OSPAR
Marine management
Vulnerable habitat
Biotope

ABSTRACT

Due to various intergovernmental agreements, marine managers must establish marine conservation measures to prevent the destruction of conservation-relevant benthic habitats e.g. Vulnerable Marine Ecosystems (VME). To aid this process, international "lists" of indicator species and habitats are created based on various conservation "criteria". As these lists are both generalised and under development, there is a need to create comparable (management) regional lists to ensure regional relevance and to propose new international "list candidates". This study provides a method to assess management region relevant (hereafter "regional")/new benthic biotopes for conservation-relevance. Quantitative criteria-linked descriptors (e.g. species richness, predicted area occupancy, etc) are used to rank biotopes, enabling a comparison between listed and new biotopes. This highlights comparatively high-ranking new biotopes as potentially conservation-relevant. In a Norwegian case study, applied to the Barents Sea management region using data from the MAREANO programme, the criteria from three international frameworks (EBSA/Azores, FAO/VME, OSPAR/Texel Faial) are assessed with descriptors obtainable from existing or future baseline datasets (video survey data, biotope classifications, and predictive biotope maps). Here, the method correctly ranks existing listed biotopes highly but it also identifies, for example, a previously unlisted biotope as potentially conservation relevant (*Cucumaria* sea cucumbers, *Eucratea* bryozoans, and *Thuiaria* hydroids on coarse bottoms with highly variable conditions). This biotope is now accepted as having regional significance warranting national conservation attention. The dominant bryozoan has also since been listed as a FAO VME indicator within ICES/NEAFC. Although demonstrated in a region with an outstanding dataset, the method is transferable to anywhere with partial baseline data that can inform biotope classification.

1. Introduction

Internationally, marine managers are faced with the task of identifying marine protection areas that satisfy international agreements and conservation criteria whilst balancing the economic needs of the community. In order to do this, they need to identify conservation targets, including benthic communities and associated habitats (hereafter collectively termed as "biotopes", *sensu* Olenin & Ducrotoy (2006)) which may suffer significant adverse impacts from human activities (Edgar et al., 2016).

The conservation target identification process is largely guided by criteria developed in parallel through multiple frameworks and agreements with different aims and regions of applicability (for a more detailed review see Garcia et al. (2014)). Most of these were prompted by the World Summit on Sustainable Development (WSSD) in 2002 which first asked nations to establish networks of Marine Protected Areas (MPAs) by 2012 (a process which, in practice, is still ongoing). For marine managers of continental shelves and offshore regions in Northern Europe, for example, several different criteria may need to be referenced depending on their region or purpose; *inter alia* those developed by the European OSlo-PARis commission (OSPAR), The Food and Agriculture Organisation (FAO), and the Convention on Biological Diversity Conference of Parties (CBD CoP). OSPAR developed the Texel-Faial criteria (OSPAR 2019, and hereafter referred to as the "OSPAR criteria") for the identification of species and habitat protection targets that signatories could use when establishing a joint European MPA

* Corresponding author.
E-mail address: Rebecca.Ross@hi.no (R.E. Ross).

https://doi.org/10.1016/j.ecolind.2023.109973
Received 12 September 2022; Received in revised form 27 January 2023; Accepted 2 February 2023
Available online 8 February 2023

network among other protection measures. The FAO, developed the Vulnerable Marine Ecosystem (VME) criteria (FAO 2009, hereafter referred to as the "VME criteria") in order to focus on sustainable fisheries, as called upon by the UN general assembly. These VME criteria are generally applied internationally via Regional Fisheries Management Organisations (RFMOs) like the Northeast Atlantic Fisheries Commission (NEAFC). Meanwhile, the CBD CoP developed the Azores criteria (CBD CoP 2008) which is used as a basis for defining Ecologically or Biologically Significant Areas (EBSAs, hereafter referred to as the "EBSA criteria"). These interpret the WSSD request with more focus on biodiversity, aiming to improve management in open-ocean waters and deep-sea habitats (within and beyond areas of national jurisdiction), including through the introduction of MPAs (Johnson et al., 2018). Note that both the OSPAR and the VME criteria tend to be applied at the biotope level, while the EBSA criteria generally operate on a larger multi-biotope scale (although biotope-level data can still be used in their assessment).

While the frameworks and criteria listed above are examples relevant to northern European marine managers, globally most coastal nations are obliged to apply similar frameworks and criteria for marine protection purposes. As all criteria have been developed in response to the WSSD, most frameworks have overlapping criteria that are directly or partially comparable with those from another framework. For example, "uniqueness or rarity" is a single criterion mentioned in both the VME criteria and the EBSA criteria, while overlapping with three criteria from OSPAR ("Global importance", "regional importance", and "rarity").

In order to speed up the process of identifying conservation-relevant biotopes according to such criteria, many international bodies have started compiling international lists (albeit within defined domains e.g. the North Atlantic) of potential qualifying biotopes, features, and/or indicator taxa. For example: OSPAR has a list of "threatened and/or declining species & habitats" (OSPAR 2008) while NEAFC has established a VME database of "VME habitats" and "VME indicators" informed by experts via the North Atlantic's International Council for the Exploration of the Sea Working Group on Deep-water ECology (ICES WGDEC, ICES, 2020). These lists are (necessarily) under constant development and have been generalised as best possible to ensure relevance to multiple nations and spatial scales.

The generalised and fluid nature of these international lists provides good reason for regional marine managers (operating on spatial scales smaller than the domain of the international lists) to seek regionally-relevant lists to supplement the international ones as a basis for regional management planning. This process can help to ensure that generalised international lists are not taken too literally, including or excluding biotopes or taxa inappropriately for the region. Furthermore, regional assessments can also help to identify new potentially conservation-relevant biotopes (hereafter termed "list candidates") that are yet to be included on the international lists and that could be proposed in the future.

Currently, new list candidates are assessed mainly by expert knowledge, but sometimes focussed studies make the case for individual habitats (e.g. Long et al., 2020). As lists must also be as generalisable as possible, some regionally relevant conservation habitats may not make it onto international lists as they are over-specific and therefore irrelevant for other regions.

This study seeks to provide a method that can supply regional list candidates based on the best available current data. The main aim is to make use of the type of baseline data that may already exist or may be obtained in the future. This is then used to generate a quantitative evidence-base that could a) support regional marine management planning with guaranteed regional-relevance, and b) be used to propose new list candidates for international consideration. The method also aims to be iterative so that new data can be integrated in the future.

2. Material and methods

The methods are described in general terms for others to replicate within their own context, however all results are presented in relation to a Norwegian case study, such that examples can be seen for each step of the process. The method was developed in consultation with the Norwegian Directorate of Fisheries who are responsible for designating fishing restrictions in Norway and who (amongst other government departments and stakeholders) already receive data and advice through the MAREANO programme and its partners (Buhl-Mortensen et al., 2015; see case study section). It was therefore important to ensure that the method use baseline survey data in order to utilise existing datasets.

2.1. Input data types

This method has been developed for application to the kind of survey data that can be used for reliable community analysis: quantitatively annotated and georeferenced video/image surveys. Video/ image data (usually obtained by towed camera or ROV) is ideal as it is non-destructive, gives a good idea of area surveyed, and can provide a near-complete profile of the epibenthic assemblages that are targeted by these conservation efforts (Durden et al., 2016). Quantitative trawl or sled data could also be used in this manner but there are considerable downsides to such methods including their destructive nature, inaccurate representations of taxon density and proportions, and even wrongly assumed dominant taxa (Jac et al., 2021). Destruction is of particular concern for VMEs, undermining both their protection and their identification. The fragile taxa that may indicate VMEs are often underrepresented in trawl/sled data as they may be fragmented and sieved out of the net before they reach the deck of the ship (e.g. cup corals, anemones, fragile gorgonians, xenophyophores, delicate glass sponges, etc; Williams et al., 2015, Lindal Jørgensen et al., 2016, Ayma and Aguzzi, 2016). Note that other species maybe underrepresented in video/image data (e.g. Annelida, Mollusca, etc; Williams et al., 2015, Ayma and Aguzzi, 2016), but these are less likely to be fundamental to the identification of conservation-relevant biotopes (i.e. those that are by definition vulnerable to destruction from human activities, Williams et al., 2015, Watling & Auster 2017). Caution is therefore advised if using trawl/sled-based datasets.

Once observations are acquired, patterns of association between species are studied in order to obtain a classification of potential biotopes in the region. Classification methods seek to sort and divide sampling units (e.g. images) into groups with similar taxon composition and dominances. This is a necessary step to provide categorical units that can act as surrogates for biodiversity (*sensu* Grantham et al., 2010) and be assessed for conservation-relevance against existing criteria. The full procedure for defining biotopes is beyond the scope of this paper, but could be achieved by using e.g. TWINSPAN groups related to environmental characters (Buhl-Mortensen et al., 2020), hierarchical cluster and SIMPER analyses (Howell et al., 2010), or with species-based sample ordinations (such as detrended correspondence analysis, DCA) expertly divided up with the guidance of environmental and dominant taxa differences (Buhl-Mortensen et al., 2009a,b). The resulting categorised biotope data forms the basis of all further assessments with this method.

Multiple data formats can be used in the evaluation process from raw species lists per biotope, to georeferenced classified points, and predictively modelled biotope maps.

Georeferenced biotope data can facilitate spatial analyses of spatially explicit metrics that assess individual criteria. Such metrics, whether spatially explicit or not, are hereafter termed as criterion "descriptors". Classified point data (e.g. shapefiles of video sample locations with biotope assignments) can be cross-referenced with, for example, a raster of chlorophyll *a* concentrations as a descriptor of biological productivity.

Georeferenced biotope data can also be used to produce full or partial coverage biotope maps by employing predictive modelling – another data type that can be used in this method. Predictive models generally use mathematical algorithms to relate georeferenced classified biotope observations to full/partial coverage environmental data. That mathematical model can then identify which biotope is most likely to be located in any given set of mapped environmental conditions in the region. This predictive modelling step is advised for quantitatively estimating rarity (i.e. areal coverage), but qualitative literature reviews can provide some insight here and most other criteria can still be assessed without such maps. Again, it is beyond the scope of this paper to detail predictive modelling procedures which range from simple classification or decision tree based or methods (e.g. Dolan et al., 2009, Robinson et al., 2011, Che Hasan et al., 2012) to more sophisticated machine learning based methods (e.g. Buhl-Mortensen et al., 2020, Piechaud et al., 2015, Elvenes et al., 2013, Gonzalez-Mirelis & Lindegarth 2012, Schiele et al., 2015, Porskamp et al., 2018). Model evaluation steps should also be taken to estimate the reliability of the maps, and ideally spatial uncertainty assessments produced and used to amend any conclusions (Dolan et al., 2021). Ultimately, the aim of the modelling procedure is to produce the most well-informed map possible, given the available input data, with as complete coverage of the management area as possible. This map, showing the most likely spatial distribution of biotopes, can then be used to calculate the spatial extent and distribution of each biotope across the region.

2.2. Converting criteria into quantitative descriptors

First, the frameworks and criteria which are relevant to the management must be identified, ideally in consultation with marine managers. For example, the case study focusses on three criteria frameworks relevant for northern Europe: the aforementioned OSPAR, VME, and EBSA criteria, Table 1. Given the level of overlap between frameworks, the case study criteria are likely to cover many of the requirements set out by other frameworks across the globe and thus offer a good starting point for similar work in other regions.

Once selected, the relevant framework criteria can then be checked for overlaps and quantitative descriptors identified. The descriptors should be linked to the criteria that they influence (see case study examples in Table 2). Criteria are generally carefully worded and often indicate useful descriptors and occasionally corresponding threshold values (see detail column in Table 1). For example, the EBSA criteria cites “biological diversity” as a qualifying criterion, defining this as an “Area [that] contains [a] comparatively higher diversity of ecosystems, habitats, communities, or species, or has higher genetic diversity” (CBD COP 2008). Therefore, metrics such as species richness and Shannon’s H are appropriate biotope descriptors, with comparatively higher values representing more conservation-relevant biotopes (see Table 2 for further examples).

Further (non-exhaustive) possible descriptors, are suggested in the supplementary material and could be added should additional data types and sources be available. This list is supported by several previous studies which have undertaken similar descriptor-finding processes (e.g. Derous et al., 2007, Clark et al., 2014, Yamakita et al., 2017), though all have different types of data available for their areas, and different study aims. This will always be the case, so it is hard to list a standard set of descriptors valid for all study areas. Therefore further descriptor searches are advisable to source ideas for other area-specific suitable descriptors.

Additional literature searches can also be useful to provide context for quantitative results coming from descriptors with only partial (criterion- or spatial-) coverage. However, literature-based descriptors are unlikely to equally assess all biotopes in the region, especially when some biotopes may be newly identified and are not yet described in the literature. Of the three framework criteria sets assessed in this study, two (of the eighteen) criteria were deemed to need exclusively different datatypes to those obtainable from baseline survey data. Both the VME “Life-history traits affecting recovery” criterion and the OSPAR

Table 1
The criteria for identifying conservation relevant biotopes/areas/ indicator species as listed by OSPAR (Texel-Faial Criteria), the FAO (VME Criteria) and the CBD (EBSA/ Azores Criteria). Details abridged from supporting literature (OSPAR 2019, FAO 2009, CBD COP 2008).

Criteria	Detail
OSPAR CRITERIA	
Global importance	e.g. > 75 % of global occurrences are within an OSPAR Area
Regional importance	e.g. > 75 % of occurrences within an OSPAR Area are within a single sub-region
Rarity	e.g. 2 % of 50 km*50 km squares per zone
Sensitivity	(Resistance low) easily/ (very low) very easily adversely affected by human activity, and/or (Resilience low) recovery from impact only after 5+/ (very low) 25 + years (NB may be different for different impacts)
Ecological significance	e.g. Supports spawning, breeding, reproduction, or nursery areas for fish, mammals or birds, has high productivity /diversity/ endemicity, important migratory route
Status of decline	Beyond natural variability: currently threatened, human-linked potential to reduce habitat extent by 15 % or more (lower threshold if rare/sensitive also). Expert judgement satisfactory.
VME CRITERIA	
Uniqueness or rarity	Unique or contains rare species and cannot be compensated for by another area/ ecosystem including functionally significant areas
Functional significance	Discrete area important for fish stocks or rare/ threatened/ endangered species
Fragility	High susceptibility to degradation by human activities
Life-history traits affecting recovery	Slow growth, late maturity, low/ unpredictable recruitment, long-lived
Structural complexity	Complex structures intrinsic and supporting high diversity
EBSA CRITERIA	
Uniqueness / rarity	Irreplaceable areas - contains unique, rare, or distinct species/ habitats or ecosystems/ geomorphological or oceanographic features
Special importance for life-history stages of species	Areas that are required for a population to survive and thrive
Importance for threatened, endangered or declining species and/or habitats	Area will ensure the restoration and recovery of endangered, threatened, declining species or has significant assemblages of such species
Vulnerability, fragility, sensitivity, or slow recovery	Contains high proportion of sensitive habitats/ biotopes/ species that are functionally fragile or with slow recovery i.e. area with degree of risk if human activities/ natural events cannot be managed effectively/ sustainably
Biological productivity	Area with comparatively higher natural biological productivity/ plays important role fuelling ecosystems/ growth rates/ reproduction
Biological diversity	Area with comparatively higher diversity of ecosystems/ habitats/ communities/ species/ genetic diversity important for maintaining resilience of species and ecosystems
Naturalness	Area with a comparatively higher degree of naturalness / lack of or low level of human-induced disturbance or degradation - provides reference site and ecosystem resilience

Table 2
List of descriptors used in the case study together with their thresholding method (and corresponding value for this dataset) and the criteria they can assess (**X**). Small symbols (x) reflect descriptors that are partial/possible descriptors, with reasons given in the last column. The two highlighted criteria (italics and dashes in rows) are not covered by these descriptors and need to be approached using different data types. Superscript letters relate to references that support descriptors and their thresholds: a) Clark et al. 2014, b) Derous et al. 2007, c) Morato *et al.* 2008, d) Yamakita et al. 2017, e) OSPAR 2019, f) Halpern et al. 2008, g) Norwegian regulation FOR-2011–07-01–755 §2.

Quantitative Descriptor	Data type used	Threshold	OSPAR CRITERIA							VME CRITERIA					EBSA CRITERIA						Reason if only a partial/ possible descriptor (light grey cells)
			Global importance	Regional importance	Rarity	*Sensitivity*	Ecological significance	Status of decline	Uniqueness or rarity	Functional significance	Fragility	*LH traits making recovery difficult*	structural complexity	Uniqueness or rarity	Import. to LH stages of species	Import. T, En, Decl spp/ habitats	Vuln./ frag./ sens./ slow recovery	Biological productivity	Biological diversity	Naturalness	
Species Richness	Video Analysis Data	> Mean + SD[a] 3.257				–	**X**			**X**		–							**X**[a]	x[b]	Expect higher values if structurally complex/ natural, but not guaranteed - requires comparison
Shannon's H (diversity)	Video Analysis Data	> Mean + SD[a] 2.941				–	**X**			**X**		–							**X**[a]	x[b]	
Commercial species richness	Video Analysis Data	> Mean + SD [a] 0.205				–	**X**			**X**		–									Possible support to LH stages of commercial spp.
Commercial species abundance	Video Analysis Data	> Mean + SD [a] 0.300				–	**X**			**X**		–					x[a]				Not necessarily fished, but indicates areas that could be future targets
Red list species richness	Video Analysis Data	> Mean + SD [a] 0.021			x	–	**X**		**X**[c]	**X**		–		**X**		**X**[a]					Multiple rare species may rarely be encountered together
Red list species abundance	Video Analysis Data	> Mean + SD [a] 4.051	x	x	x	–	**X**		**X**[c]	**X**		–		**X**		**X**[a]					It could be rare/ significant to encounter abundant rare species
Likely < 2 % in area (% pixels + literature)	Biotope Maps	Occupies < 2 % of pixels[e] + likelihood check			**X**	–			**X**			–		**X**							
Chlorophyll *A*	Bio-Oracle raster + Sample Maps	Highest 5 %[a] but adjusted for depth (Fig. 2)				–	x			x		–						**X**[a]			Productivity is only one facet of ecological/ functional significance
Average Halpern et al. 2008 Human Impact score	Halpern raster + Sample Maps	Medium or lower[f] < 8.47, High > 12				–		x[d]			x	–					x			**X**[d]	Suggests only higher likelihood of decline where

(*continued on next page*)

Table 2 (*continued*)

Quantitative Descriptor	Data type used	Threshold	OSPAR CRITERIA: Global importance	Regional importance	Rarity	*Sensitivity*	Ecological significance	Status of decline	VME CRITERIA: Uniqueness or rarity	Functional significance	Fragility	*LH traits making recovery difficult*	structural complexity	EBSA CRITERIA: Uniqueness or rarity	Import. to LH stages of species	Import. T, En, Decl spp/ habitats	Vuln./ frag./ sens./ slow recovery	Biological productivity	Biological diversity	Naturalness	Reason if only a partial/ possible descriptor (light grey cells)
																					impact is high
Predominance relative to trawling depth	Multibeam bathymetry + Sample Maps	>1000 m [g]				–		x			x	–					x			x[a]	Binary, unrankable, but can be useful as a thresholding metric (above threshold = poss. vulnerable, below = poss. natural)

"Sensitivity" criterion require species intrinsic data about the reproduction and aging of the dominant species in each biotope in order to make an assessment. These are the only criteria where no attempt is made to assess them, and for which a literature-only approach is likely to be necessary. Note that these partially overlap with the EBSA "Vulnerability, fragility, sensitivity, or slow recovery" criterion which is therefore only partially assessed. Criteria that need literature-only information are not covered by this method.

2.3. *Converting quantitative desciptors into potential conservation-relevant biotopes*

All descriptors suggested in this case study are intentionally quantitative. This allows a threshold value to be used to highlight biotopes that may potentially qualify as conservation-relevant. All thresholds were based on advice obtained from literature searches, but otherwise default to assuming that descriptor values should be higher than the mean + the standard deviation relative to the rest of the study area dataset in order to be considered for qualification (in line with Clark et al., 2014). Therefore, thresholds are over-generous and precautionary, allowing too many biotopes to be retained as potentially conservation-relevant. Further evaluations are recommended before assuming conservation-relevance has been proven.

Note that some descriptors are only appropriate to consider when they are present together with others that surpass the thresholds (hereafter termed "partial descriptors", examples from the case study are marked with a small "x" in Table 2). For example, descriptors representing impact also need to be accompanied by an indicator of ecological importance or sensitivity to impact (but, as explained above, the latter is not covered in this study). Without these the biotope may just be one that thrives in an impacted area and therefore may not warrant conservation attention.

While the raw descriptor values themselves should be delivered to marine managers, a ranked summary is advised to ensure that new biotopes are easily compared with the internationally listed biotopes in terms of their conservation-relevance. The simplest approach to this summary step is to a) rank all descriptor values, displaying only biotopes that surpass thresholds, b) summarise ranks per criterion across descriptors retaining maximum ranks per biotope, and c) identify and highlight biotopes covered by international lists. By comparing new biotopes with biotopes that are covered by international lists it can quickly be seen which are of greatest potential conservation-relevance.

Care must also be taken to ensure that the short-list is evaluated further to understand which descriptors have contributed to their criteria rankings. If, for example, only one descriptor has resulted in a high rank within multiple criteria then there are possible grounds to down-weight that biotope's perceived importance until additional evidence is available. However, this needs considering on a case by case basis before recommendations are made to or by the management authorities.

Completion of this summary step provides the short-list of candidate regionally conservation-relevant biotopes. An example of this entire process, together with the final list of potential regional conservation-relevant biotopes that it highlights, are presented in the case study below.

2.4. *Case Study: Norwegian Barents Sea*

MAREANO is a multi-institute seabed mapping programme that has been supplying baseline survey data to the Norwegian government and management agencies (as well as other interested parties) since 2006 (Buhl-Mortensen et al., 2015). While MAREANO collects multiple types of samples and data (e.g. using multibeam bathymetry, Van Veen grab, beam trawl, Rothlisberg-Pearcy sled, multicorer, boxcorer, and sub-bottom profiler) the majority of observations are collected by towed video camera ("CAMPOD" or "Chimaera" as described in Buhl-

Mortensen et al. (2009a,b) and Buhl-Mortensen and Buhl-Mortensen (2017), respectively). MAREANO and its partners currently supply data and advice about conservation-relevant biotope distribution based on MAREANO's extensive quantitatively annotated video dataset (MarVid) together with the international lists of qualifying habitats and indicator species (Gonzalez-Mirelis et al., 2021, ICES 2020). The method proposed here supplements these existing procedures to ensure that regional conservation-relevant biotopes are also identified.

This study was undertaken in the Norwegian Barents Sea Management Region (Fig. 1 B inset). MAREANO survey data provided good yet partial coverage in this region, and biotope classes and biotope maps have already been created and published with this dataset (Buhl-Mortensen et al., 2020).

This study utilises MAREANO's MarVid dataset, in which all visible fauna are recorded and counted. Species are identified to the highest taxonomic resolution possible, with descriptive morphological names applied where it is not possible to identify them further.

The case study dataset comprises of 757 video transects which can be split into 2913 ~ 225 m-long viable video samples with biological community data comprised of 222 identified taxa. This data has been used to identify 27 biotopes using a TWINSPAN classification method (Table 3) and produce a biotope map (Fig. 1, see Buhl-Mortensen et al. (2020) for details). The biotope map and video observations cover only the area surveyed by MAREANO with high resolution multibeam data before 2020, so the analysis presented in this case study cannot be considered complete for the entire management region.

Nevertheless, the mapped area is sufficiently extensive to serve as a proof of concept, and it is realistic that similar partial coverage datasets and maps may be what is available in other regions, globally. Thus, for spatial coverage descriptors (i.e. those that help quantify uniqueness and rarity and utilise biotope maps) a literature-based assessment was also conducted to adjust the conclusions drawn from a partial-coverage dataset (e.g. when additional observations were noted in the region by other datasets).

For Norway, the EBSA criteria were deemed to be of particular interest as recommendations for national management areas termed "particularly valuable and vulnerable areas" ("særlig verdifulle og sårbare områder (SVO)") are based on these criteria. However, Norway also utilises the VME descriptions in offshore fisheries management, and is a member of OSPAR with designated OSPAR MPAs, so there was also interest in referring to these three criteria sets, Table 1.

The main criteria overlaps between these three frameworks can be summarised as those describing:

- **Spatial rarity** i.e. the EBSA and VME "Uniqueness or rarity" criteria or a combination of OSPAR's "Rarity", "Global Importance" and "Regional Importance" criteria.

A

A	B	C	D	E	F
xSubsample	Taxon_cleaned	Count	X_UTM33N	Y_UTM33N	Biotope
508_531_4	Melanogrammus aeglefinus	1	883929.9542	7950553.104	J
508_531_4	Parastichopus tremulus	3	883929.9542	7950553.104	J
508_531_4	Porifera encrusting	20	883929.9542	7950553.104	J
508_531_4	Solaster endeca	2	883929.9542	7950553.104	J
508_531_4	Trisopterus esmarkii	4	883929.9542	7950553.104	J
509_532_1	Aplysilla sulfurea	2	883001.4906	7943939.432	K
509_532_1	Axinellidae	2	883001.4906	7943939.432	K
509_532_1	Echinus	15	883001.4906	7943939.432	K
509_532_1	Henricia	3	883001.4906	7943939.432	K
509_532_1	Hymedesmia paupertas	1	883001.4906	7943939.432	K
509_532_1	Lumpenus	1	883001.4906	7943939.432	K
509_532_1	Parastichopus tremulus	1	883001.4906	7943939.432	K

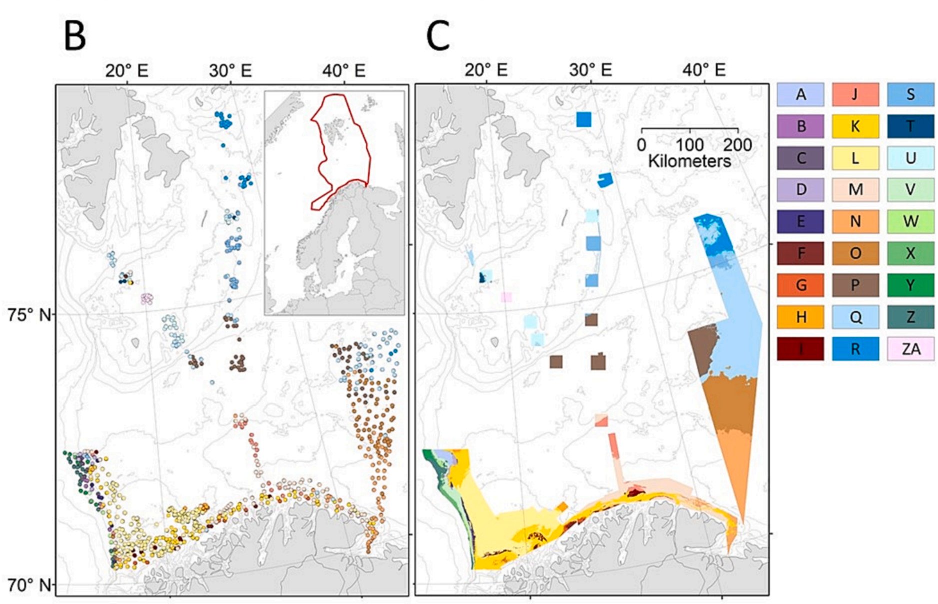

Fig. 1. The input data types and the case study area. (A) example records showing biotope classified community data inclusive of taxa, counts, and georeferencing. This kind of data can then be mapped as biotope observations (B), and predictively mapped across the area with environmental predictor coverage at appropriate resolution (C). This case study is located in the Barents Sea management region of northern Norway (B, inset), and utilises biotope classifications (here indicated by letters A-ZA, see Table 3 for descriptions) and predicted maps already published in Buhl-Mortensen et al. (2020) and on www.mareano.no Contours derived from GEBCO 2019 bathymetry (gebco.com).

Table 3
Biotic descriptions of biotopes defined by Buhl-Mortensen et al. (2020) – fuller descriptions including environmental profiles are available in the original paper. Note that biotope complex, L, consists of more than one potential biotope due to *Lophelia* reef having<20 samples in the region (i.e. it was too rare).

Biotope	Description
A	Pigtail coral (*Radicipes*) garden
B	Cauliflower corals
C	Encrusting sponges, tunicates, and cauliflower corals
D	*Tethya* and *Craniella* sponges
E	*Phakellia* sponges
F	Encrusting red algae
G	Sea pens and Cauliflower corals
H	*Asbestopluma* sponges and cup corals
I	Cup corals
J	*Reteporella* bryozoan
K	Sponge garden
L	Soft bottom sponge aggregation/*Lophelia* Reef
M	Sea urchins, *Parastichopus* sea cucumber and *Kukenthalia* tunicate
N	*Filograna* polychaetes and small sponges
O	*Liponema* anemones
P	Bryozoans and filamentous *Suberites* sponges
Q	*Psolus* (Holothurian) and Cauliflower corals (*Gersemia rubiformis*)
R	Basket star aggregations
S	Cauliflower corals (*Gersemia rubiformis*) and *Porella* bryozoans
T	Cauliflower corals and tube anemones (Cerianthidae)
U	Iceland scallop aggregations
V	*Virgularia* sea pens
W	*Umbellula* sea pens
X	Encrusting sponges
Y	Cold-water carnivorous sponges and leeches
Z	Tube anemones and cold-water carnivorous sponges
ZA	Sea cucumber (*Cucumaria frondosa*), *Thuiaria* hydrozoans and *Eucratea* bryozoans

- **Ecological importance** i.e. OSPAR's "Ecological Significance" is approximately equivalent to a combination of VME's "Functional Significance" and "Structural Complexity", or EBSA's "Biological Productivity", "Biological Diversity", "Importance for threatened, endangered or declining species and/or habitats", and "Special importance for life-history stages of species" criteria.
- **Impact likelihood** i.e. EBSA's "Vulnerability, fragility, sensitivity, or slow recovery" is roughly equivalent to a combination of OSPAR's "Status of Decline" and "Sensitivity", or VME's "Fragility" and "Life-history traits affecting recovery" criteria.

The EBSA criterion "Naturalness" had the least overlap with other framework criteria. However, as naturalness implies a lack of impact, some quantitative descriptors can be used inversely to help assess both impact and naturalness.

After identifying intuitive criteria-linked descriptors and searching the literature for additional solutions, Table 2 shows the case study descriptors and partial descriptors, the data types used to assess them, the applied thresholding rules and area-specific values, the criteria the descriptors can assess, and some supporting literature. "Partial descriptors" are here only considered when a non-partial descriptor also surpasses its threshold.

Generally, georeferenced species id and count data were used for quantitative descriptors contributing towards criteria related to ecological importance (Species Richness, Shannon's H, Commercial Species Richness/Abundance, Red List Species Richness/Abundance). All of these were calculated, based on the MarVid data cross-referenced with regional red list and commercially exploited lists for the management region, summarised per biotope, and adjusted for the number of samples within that biotope (value/number of samples per biotope).

Biotope maps were used to assess rarity in the region (suggested by OSPAR as occupying < 2 % of the area), utilising proportions of pixels to compare with the 2 % threshold. Additional literature checks were then used to see if these partial-area results were likely to be refuted or confirmed when applied to the whole region.

Georeferenced biotope data were also related to environmental data (rasters) from external sources in order to generate some descriptors. The Chlorophyll *a* assessment used a "mean Chlorophyll at mean bottom depth" raster downloaded from Bio-Oracle (https://www.bio-oracle.org/). Although coarsely resolved (5 arc-minutes, ~9.2 km at the equator/ ~8km in this study area), this variable could be used to approximate whether some biotopes occur in averagely higher productivity regions than others. However, as chlorophyll *a* concentration decreases with depth, it is inappropriate to use the mean + SD threshold rule (after Clark et al., 2014) which may only highlight shallow biotopes. The threshold was therefore decided to be the upper 95 % confidence interval for chlorophyll *a* values relative to average biotope depth (Fig. 2). Yamakita et al. (2017) suggested the use of Halpern et al.'s (2008) global Human Impact model results (hereafter referred to as the "Halpern HI score") which, although coarsely resolved, combines multiple potential impacts into one index. While multiple regional data sources would be preferable, the Halpern HI score model output can offer an objective approximation for both impact and naturalness criteria that is easy to access and is globally relevant.[1] Impact thresholds in this study utilised Halpern et al.'s (2008) suggestions which defined all values over 12 as high or very high impact, while values below 8.47, listed as medium or lower impact, were used as a proxy for EBSA's "naturalness" criterion. Finally, multibeam bathymetry data (which could be replaced by GEBCO global bathymetry data if higher resolutions are unavailable) was used in tandem with Norwegian legal depth-restrictions on bottom fishing to assess the susceptibility to impact or probability of naturalness using depth as a proxy. At the time of this study, bottom fishing is restricted to 1000 m for the majority of this management region, although in the Svalbard benthic protection area, restrictions have been amended to 800 m and even shallower across the Yermak Plateau.[2] By showing the depth values for each biotope (even when all fall above the 1000 m restriction, as they do in this study) marine managers are at least equipped to see which biotopes might be protected should further sub-regions be amended to a shallower depth limit.

3. Results

Table 4 shows the values for all descriptors per biotope from the case study region, with all values above the thresholds (listed in Table 2) highlighted as potentially conservation-relevant values. Note that average depth values are provided for reference in Table 4, but additional depth information is available in supplementary material (min/max/SD).

Twenty of the 27 biotopes seem to display potentially qualifying values in at least one descriptor. This is likely too many to be practical protection targets, but further assessment does refine this list. Five biotopes (F, G, I, M, T) require further information before they could be deemed as qualifying, as thresholds are only surpassed for partial descriptors (highlighted in the last column of Table 4) – these will not be assumed to be conservation-relevant biotopes at this time but should be investigated further.

Table 5 consolidates the per-descriptor data from Table 4, taking all qualifying values, ranking them relative to each other, and displaying the highest rank of any one descriptor per criterion. This is because each criterion may be inclusive of multiple descriptors (in Table 5, contributing descriptors are listed as roman numerals corresponding with descriptor numerals in Table 4). Table 5 also contains an evaluation of whether biotopes might already appear on international lists.

[1] Halpern HI score raster was downloaded from https://knb.ecoinformatics.org/view/doi%3A10.5063%2FF19C6VN5#urn%3Auuid%3A110fd4d9-88c7-4f31-9422-cb9bf7e73d1a (accessed 06.09.2022).

[2] Regulation FOR-2011–07-01–755 §2 amended 1st July 2019, available in Norwegian at https://lovdata.no/dokument/SF/forskrift/2011–07-01–755, accessed 06.09.2022.

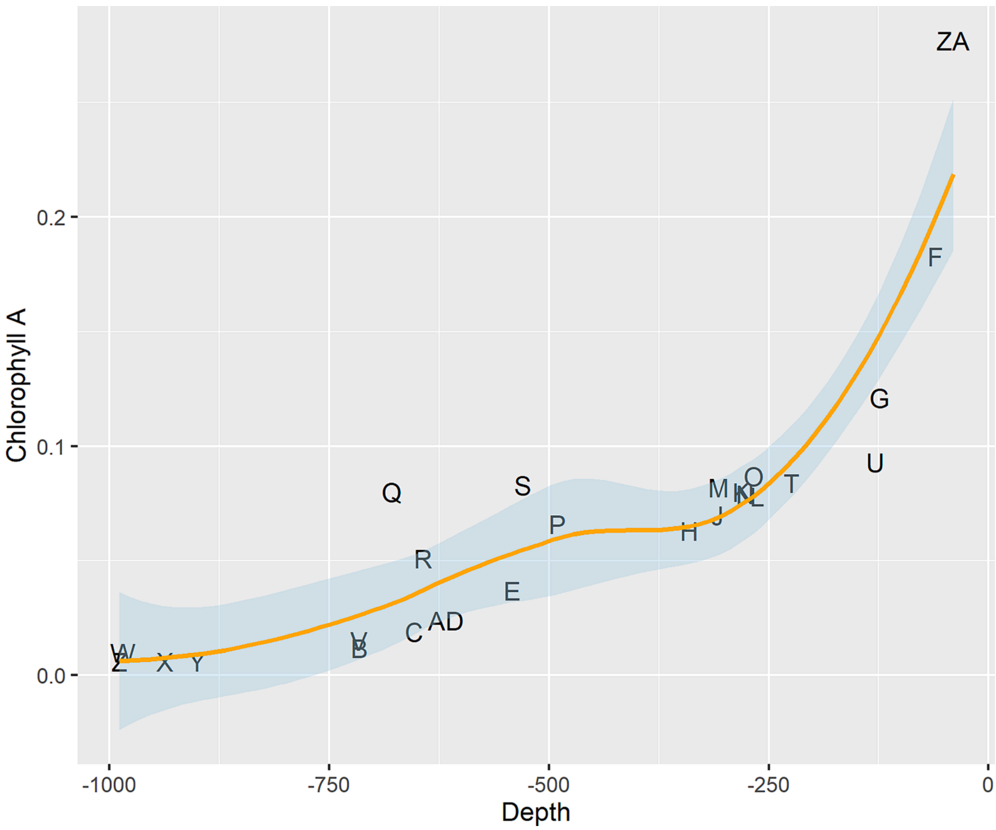

Fig. 2. Bottom Chlorophyll *a* values per biotope adjusted for depth. Letters correspond with biotopes in Table 3. A high value threshold would highlight only the shallowest biotopes (i.e. ZA, F) which is not the intention of this predictor. Instead the 95% confidence interval was used as a threshold, showing three biotopes (ZA, Q, S) with particularly high chlorophyll *a* values for their average depth. This is an example of using environmental data from external sources (here Bio-Oracle) to combine with georeferenced biotope data to form the basis of a descriptor.

This step refines the list of 15 qualifying biotopes down to three qualifying biotopes which would be overlooked by international lists, but which may be considered conservation relevant. These are biotopes J (dominated by *Reteporella* bryozoans), R (i.e. *Gorgonocephalus* sp. basket star aggregations), and ZA (*Cucumaria frondosa* sea cucumbers, *Thuiaria* hydrozoans and *Eucratea* bryozoans) (Fig. 3).

Biotope J's qualifying features are in its biological diversity combined with a high potential for impact (Table 5). This interpretation is based on two descriptors that surpass the thresholds (Table 4): Shannon H diversity, and a high average Halpern HI score. Considering the context further, the high relative diversity of this biotope is certainly of conservation interest, ranking third most diverse after two already internationally listed sponge and soft coral biotopes (H and C). Furthermore, this biotope is mostly found on mixed coarse sediments which could be targeted by trawl fisheries. However, the Halpern HI score is based on a very coarse map, so further assessment is advised based on finer resolution and up-to-date information. It is also worth assessing the sensitivity to impact of the constituent fauna. Provisionally, as *Reteporella* spp are upright and brittle these could be destroyed by fishing gear, which may further qualify this biotope for conservation targeting in the future. Additional checks will be made (e.g. density, coherence, patchiness) of this biotope before proceeding to advocate for its protection.

Biotope R has only one qualifying criterion under the EBSA criteria – that it may be an example of "naturalness" due to there being a particularly low impact score in the area. This is based solely on a low Halpern HI score and needs to be evaluated further with regional data at a resolution suitable for management measures. However, this conclusion is supported by a study in the Bering Sea (McConnaughey et al., 2000) that suggests that Gorgonocephalids prefer lower impact (unfished) areas. Further research may support considering this biotope as rare or unique too as, while Gorgonocephalids are considered to be gregarious (and can be found all over the world), there are few published records of larger aggregations where they dominate the benthos as they seem to in this region (Lindal Jørgensen 2016). With varying densities of *Gorgonocephalus* spp. in the samples that contribute towards the biotope definition in this particular dataset, however, again additional checks are needed to verify the biotope before proceeding further in the recommendation process.

Biotope ZA is the strongest potential list candidate. It also bears some resemblance to a community identified on the Tail of the Grand Bank in the NW Atlantic dominated by *Eucratea loricata* and hydroids from the same family as *Thuiaria* (Murillo et al., 2016). Table 5 shows that it qualifies in terms of its limited spatial distribution, high biological productivity, and naturalness, with Table 4 clarifying that there are three descriptors contributing to these assessments. Both Table 4 and Table 5 show that this biotope ranks the highest in each of these categories (i.e. occupies the smallest area, has the highest relative chlorophyll *a* concentration for its depth, and has the lowest average Halpern HI score). Arguably the chlorophyll *a* concentration and the low Halpern score require further investigation. This biotope is found shallower than the others being considered and the chlorophyll *a* values may be comparable to other unsampled shallow water biotopes in the region. The low Halpern HI score, being derived from a coarse global model, should be assessed relative to regional vessel monitoring system (VMS) data, but it is encouraging at this resolution, nonetheless. However, the small spatial distribution in this region is relatively certain and of particular conservation interest.

The biotope analysis that identified this biotope (Buhl-Mortensen et al., 2020) also highlighted that biotope ZA was found in particularly unusual environmental conditions i.e. in areas with highly variable temperature, salinity and strong current speeds, where the substrate is mostly sand (Bellec et al., 2019). Indeed, this biotope appears as an outlier in both species' composition and environmental conditions, further supporting the biotope's authenticity as both a biotope and a list candidate. There is potential that this biotope may be found to cover more of Spitsbergenbanken where these observations originate from (and further surveys are planned to check this), but, based on current

Table 4
Descriptor values for each biotope in the region (biotopes described in Table 3). Column numbers as roman numerals correspond with those in Table 5 (grouped per criterion). Highlighted cells (black bold/ italic) are above the threshold listed in Table 2. Biotopes in italics qualify only with "partial descriptors" (columns iii, iv (a), iv (b), ix (a)) and must be disqualifying until more information can be supplemented. Note that chlorophyll *A* values are shown (viii) but pass the threshold only when are outside 95 % confidence intervals moderated for depth - see Fig. 2. None of the average depths (column x) surpass the 1000 m trawling limit threshold, but values are still shown here, both for consideration with chlorophyll *a* and as a means of assessing whether a shallower trawl limit could be beneficial for protection plans. Further depth information (min/max/SD) is available in the supplementary material.

Biotope	**i.** Species Richness	**ii.** Shannon H (diversity)	**iii.** Comm. species richness	**iv (a).** Comm. species abund.	**iv (b).** Comm. species abund. (Inc *P. borealis*)	**v.** Red list species richness	**vi.** Red list species abund.	**vii.** Likely < 2 % in area (pixels + literature)	**viii.** Chl. A (but consider relative to depth **x**)	**ix (a).** High Av. score Halpern human impact	**ix (b).** Low Av. score Halpern human impact	**x.** Average Depth (1000 m trawl ban)
A	3.100	2.819	0.200	0.052	0.052	**0.025**	**17.167**	**0.724**	0.024	10.375	10.375	−627.713
B	2.964	1.755	0.143	0.037	0.037	**0.036**	0.068	0.165	0.012	10.143	10.143	−715.590
C	**5.500**	**3.291**	**0.292**	0.082	0.082	**0.042**	0.017	0.038	0.019	10.219	10.219	−653.058
D	**4.385**	2.608	**0.308**	0.051	0.051	0.000	0.000	0.266	0.024	10.358	10.358	−606.765
E	**3.870**	2.357	**0.261**	**0.368**	0.368	**0.043**	0.043	0.047	0.037	10.851	10.851	−541.607
F	2.444	1.060	*0.250*	*0.536*	*0.536*	0.000	0.000	0.339	0.183	*15.204*	15.204	−60.329
G	1.778	1.362	*0.204*	*0.547*	*0.547*	0.019	0.056	0.653	0.121	*15.571*	15.571	−123.760
H	1.306	**3.375**	0.118	0.165	0.165	0.012	0.588	0.384	0.063	**12.679**	12.679	−340.094
I	1.500	1.743	0.162	*0.313*	0.313	0.014	0.824	0.067	0.078	*13.845*	13.845	−283.777
J	1.528	**3.068**	0.130	0.205	0.205	0.000	0.000	1.499	0.070	**12.095**	12.095	−307.849
K	0.702	1.532	0.050	0.082	0.114	0.005	0.188	10.521	0.080	**13.688**	13.688	−281.100
L	0.493	0.575	0.032	0.046	0.046	0.005	0.378	14.926	0.078	**13.295**	13.295	−263.198
M	1.022	2.579	0.076	0.118	0.208	0.004	0.302	7.937	0.082	*12.420*	12.420	−306.999
N	0.682	2.639	0.061	0.080	0.219	0.000	0.000	8.719	0.079	10.689	10.689	−276.861
O	0.647	2.389	0.060	0.068	0.364	0.005	0.005	10.990	0.087	9.300	9.300	−267.312
P	0.943	2.092	0.082	0.093	0.462	0.000	0.000	6.546	0.066	9.223	9.223	−490.105
Q	0.895	2.520	0.064	0.123	0.275	0.000	0.000	20.889	**0.080**	9.306	9.306	−678.764
R	1.681	2.482	0.130	0.231	0.231	0.000	0.000	4.609	0.051	7.122	**7.122**	−642.997
S	1.283	2.832	0.123	**0.333**	**0.794**	0.009	2.263	3.129	**0.083**	10.747	10.747	−529.364
T	1.590	2.321	0.148	0.206	*1.244*	0.000	0.000	0.176	0.084	9.011	9.011	−224.286
U	1.262	2.037	0.084	0.151	0.151	0.000	0.000	2.641	0.093	8.587	8.587	−128.189
V	2.604	2.823	0.094	0.023	0.023	0.000	0.000	**1.740**	0.015	10.211	10.211	−715.869
W	**3.794**	0.316	0.118	0.105	0.105	0.000	0.000	0.460	0.010	9.947	9.947	−984.910
X	2.152	0.264	0.065	0.010	0.010	0.000	0.000	0.621	0.006	10.145	10.145	−936.693
Y	2.871	2.512	0.097	0.021	0.021	0.000	0.000	0.357	0.006	10.033	10.033	−899.937
Z	2.170	0.196	0.085	0.036	0.185	0.000	0.000	1.130	0.006	10.720	10.720	−988.899
ZA	0.630	0.726	0.074	0.106	0.106	0.000	0.000	**0.427**	**0.277**	3.973	**3.973**	−40.161

analyses, there appear to be few other patches in the management region that seem likely to host it. While more investigations can be done to support or reject the potential qualifying descriptors and criteria, a precautionary approach to rarity would advise considering biotope ZA, in particular, as a potentially conservation-relevant biotope worthy of marine management attention. This is therefore the main biotope that should be highlighted to marine managers at present.

A further two of the ten biotopes not already on international lists surpass the thresholds only for partial descriptors (Table 5). These biotopes also require follow up studies, especially evaluating sensitivity to impact, to assess whether they might qualify. These are biotopes F (dominated by encrusting red algae) and M (a community of regular sea urchins, *Parastichopus* sea cucumbers and *Kukenthalia* tunicates).

Provisionally biotope F seems hard to convince marine managers to pay attention to. It is found in shallower waters on hard rocky substrates which may already be avoided by fisheries due to the risk of nets being snagged in such areas – something not captured at the Halpern HI score raster resolution. Furthermore, the characterising encrusting red algae is unlikely to be particularly sensitive to impact, being encrusting and hardened in nature, but the accompanying fauna could still harbour some level of sensitivity. Biotope M, despite ranking lower than F, may have more traction with marine managers upon further inspection. This is mostly on the basis of the *Kukenthalia* tunicates which may potentially be sensitive to impact, being soft-bodied, sedentary, and protruding from the seafloor. The urchins and *Parastichopus* sea cucumbers are also potentially sensitive, in that they can be caught in nets, and/or injured/ killed by encounters with fishing gear, however these are mobile species which may migrate into the area again after impact, so have a higher potential for recovery than sedentary species reliant upon larval influx for recolonisation.

Note that two biotopes included on international lists would not be highlighted using this method. They are biotopes Y (Cold-water carnivorous sponges and leeches) and Z (Tube anemones and cold-water carnivorous sponges). Both of these biotopes may still qualify based on current knowledge of life history and sensitivity information which are the criteria that this method does not currently consider. It is also possible that higher density patches could qualify, while sparser patches have lowered average values (e.g. for species richness/abundance). Regardless of the reasons in this case, investigating the conservation relevance of already listed biotopes is not what this method is designed for, is not achievable using this method alone, and is beyond the scope of this exercise.

4. Discussion

This study aimed to demonstrate a method for identifying and evidencing conservation-relevant biotopes that can be given to marine managers to ensure that regional biotopes are not overlooked when planning marine management and/or conservation objectives. The Norwegian Barents Sea case study demonstrates an application of this method: using baseline epibenthic video survey data and its derivatives to generate quantitative descriptors of conservation criteria that can be ranked and used to highlight new biotopes that may have similar conservation relevance to listed habitats.

Note that the near unparalleled baseline data coverage of the MAREANO program, as used in the case study, is not a prerequisite – partial datasets can also be subjected to this method, but care must be given to understand the biases present in the dataset and the implications of these upon the recommendations given.

Of the 27 biotopes in this case study, this method highlighted three

Table 5
Maximum ranks of qualifying biotopes across descriptors per criterion (roman numerals reflect descriptor numbers in Table 4). Only biotopes with at least one descriptor value above the conservation-relevance threshold are retained here. "Sensitivity" & "Life-history traits affecting recovery" are not covered by these descriptors and need to be approached using different data types. Five highlighted biotopes (F, J, M, R, ZA) qualified and were not already on international lists at the time of the study. Black outlines highlight the three biotopes (J, R, ZA) that qualify with more than partial descriptors. Note that ZA has since been nationally and internationally listed.

Biotope	**Criteria**	**OSPAR CRITERIA** Global /Regional Importance	Rarity	Sensitivity	Ecological significance	Status of decline	Uniqueness or rarity	**VME CRITERIA** Functional significance	Fragility	LH traits….	structural complexity	**EBSA CRITERIA** Uniqueness or rarity	Import. to LH stages of species	Import. T, En, Decl spp/ habitats	Vuln./ frag./ sens./ slow recovery	Biological productivity	Biological diversity	Naturalness	**Already on VME/ OSPAR lists**	**Potential non-listed conservation-relevant biotopes**	**Number of qualifying descriptors (noted if all are partial)**
	Descriptors	vi	v, vi, vii	-	i, ii, iii, iv (a), iv (b), v, vi, viii	iv (a), iv (b), ix(a)	v, vi, vii	i, ii, iii, iv (a), iv (b), v, vi, viii	iv (a), iv (b), ix (a)	-	i, ii	v, vi, vii	iii, iv (a), iv (b)	v, vi,	iv (a), iv (b), ix(a)	viii	i, ii, v	i, ii, ix (b)			
A	1	2	–	1		2	1		–		2		1					Y		3	
B		3		3		3	3				3		3			3		Y		1	
C		2	–	1		2	1		–	1	2	2	2			1	1	Y		4	
D			–	1			1		–	2		1				2	2	Y		2	
E		1	–	1	3	1	1	3	–	3	1	3	1	3		1	3	Y		4	
F			**–**	**2**	**2**		**2**	**2**	**–**			**2**		**2**				**N**	**Encrusting red algae**	**4 (all partial)**	
G			–	1	1		1	1	–			1		1				Y		4 (all partial)	
H			–	1	6		1	6	–	1				6		1	1	Y		2	
I			–	5	3		5	3	–			5		3				Y		2 (all partial)	
J			**–**	**3**	**8**		**3**	**8**	**–**	**3**				**8**		**3**		**N**	***Reteporella* bryozoans**	**2**	
K			–		4			4	–					4				Y		1	
L			–		5			5	–					5				Y		1	
M			**–**		**7**			**7**	**–**					**7**				**N**	**Regular sea urchins, *Parastichopus* sea cucumbers and *Kukenthalia* tunicates**	**1 (all partial)**	
Q			–	3			3		–						3			Y		1	
R			**–**						**–**								**2**	**N**	**Basket star aggregations**	**1**	
S			–	2	2		2	2	–			2		2	2			Y		3	
T			–	1	1		1	1	–			1		1				Y		1 (all partial)	
V		3	–			3			–		3							Y		1	
W			–	4			4		–	4						4	4	Y		1	
ZA		**1**	**–**	**1**		**1**	**1**		**–**		**1**				**1**		**1**	**N**	**Sea cucumber, hydrozoans, bryozoans**	**3**	

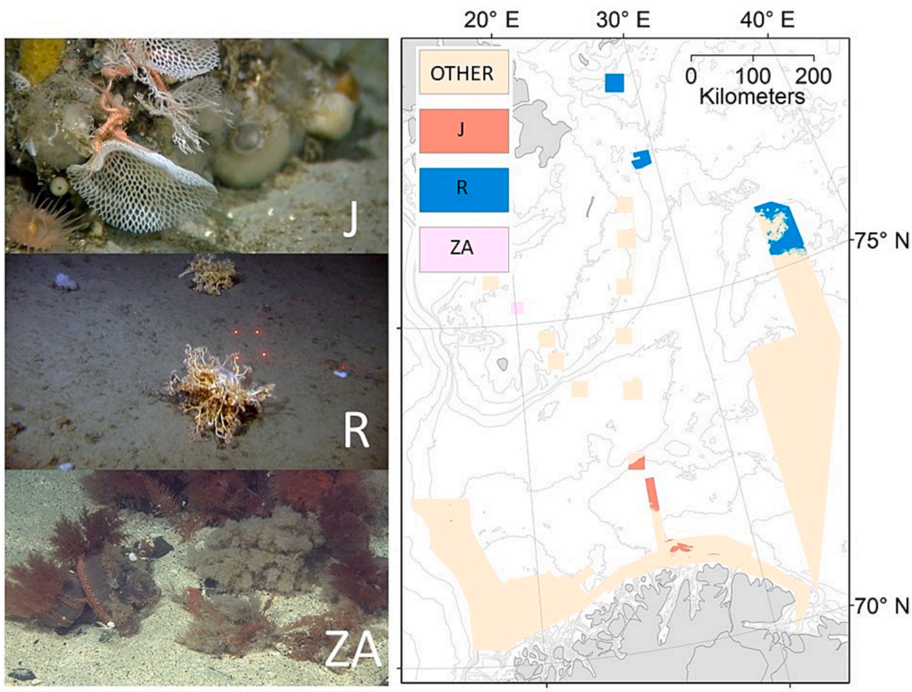

Fig. 3. Example images and biotope map of the three potential conservation-relevant biotopes identified by this process in the case study region (Barents Sea, Norway): Biotope J (dominated by *Reteporella* bryozoans), Biotope R (aggregations of *Gorgonocephalus* basket stars), and Biotope ZA (*Cucumaria* sea cucumbers, *Eucratea* bryozoans, and *Thuiaria* hydrozoans). Biotope map based on Buhl-Mortensen et al. (2020) and www.mareano.no. Contours derived from GEBCO 2019 bathymetry (gebco.com).

(at the time) unlisted biotopes that are potentially worthy of marine management attention and that would otherwise be overlooked if relying solely upon international lists. Whilst two of these three biotopes should be subject to some additional checks, one biotope (biotope ZA) may be considered ready for consideration based on the existing evidence-base.

Biotope ZA is now confirmed as both a nationally and internationally listed conservation-relevant habitat in the case study region. Nationally it had been highlighted by expert opinion since 2017 and was the basis for the Fisheries Directorate request that we must find a method that will highlight and evidence newly discovered biotopes as potentially conservation-relevant. This study fulfils that need whilst strengthening the evidence-base for national protection measures. Internationally, the FAO explicitly say that VME examples may include "iii) Communities composed of dense emergent fauna where large sessile protozoans (xenophyophores) and invertebrates (e.g. hydroids and bryozoans) form an important structural component of habitat" (FAO 2009), but the ICES/NEAFC list had only generically included "bryozoan patches" until 2019, with no associated taxa listed. Biotope ZA, as a mixed community, was not a good match for this description. The bryozoan *Eucratea loricata* is included as a VME indicator taxon on the North Atlantic Fisheries Organisation (NAFO) list (covering the western Atlantic) but when NEAFC and NAFO lists were compared in 2013, similar aggregations had not been found in NEAFC waters (ICES 2013). Therefore, MAREANO's observations were reported to ICES via WGDEC, and together with NAFO's recognition, and Murillo *et al.*'s justification, has led to *Eucratea loricata* being added to ICES/NEAFC's list (ICES 2020) (after this study had been conducted).

Whilst the effectiveness of this method can be evidenced by the emergence of biotope ZA as a list candidate, this case study does draw attention to a few issues that should be considered in future applications of this method.

Since there can be different purposes behind a biotope classification, it is possible that some biotopes are not suited to being subjected to this process, whether they are defined by pre-existing, more abiotic-based classification schemes e.g. EUNIS (Galparsoro et al., 2012), CMECS (FGDC, 2012), EcoSyst/NiN (Halvorsen et al., 2020) or data-driven and more biotically defined methods as in this case-study. Even when attempting to use an objective method, there can be a lot of subjective decisions made in the process of biotope classification, e.g. spatial scale and level of similarity. Many of these decisions are made with a particular purpose in mind. The biotopes in this case study were defined by Buhl-Mortensen et al. (2020) where the focus was on trying to define biotope units suitable for modelling. With this aim, it is acceptable that some potentially distinct biotopes may be merged with others in order to ensure that there are enough samples to use as a basis for modelling, or to minimise spatial uncertainty of predicted model outputs (Dolan et al., 2021). Biotope L is one such example, forming a biotope complex that includes both soft-bottom sponge aggregations and *Desmophyllum pertusum* reef, consolidated on the basis that *Desmophyllum pertusum* reef had < 20 samples to support it as its own mappable biotope in this management region. Were the biotopes to be defined with the aim of a conservation assessment such as this one, such a merge would not be advisable, as, by having too few samples (but still being a recognisable independent biotope) *Desmophyllum pertusum* reef would qualify as rare in this study region and therefore become more conservation relevant. While the rarity criterion could be inferred from the Buhl-Mortensen et al. (2020) biotope set knowing that this decision was taken, all further conservation-relevant descriptors could not be generated for an independent *Desmophyllum pertusum* reef biotope while records are merged into biotope complex L. Luckily in this case, *Desmophyllum pertusum* reef is already included on international lists and would have been ignored anyway, but the example demonstrates that analytical decisions and classification purpose can affect whether all possible regional conservation-relevant biotopes are captured using this method.

There are also remaining questions about biotope community density. It makes sense that there may be a critical density that would make a biotope become conservation-relevant. However qualifying density thresholds are both under debate and likely to be biotope (and possibly regionally) specific, so have not been evaluated here. Operating at the biotope level also means that density is not necessarily uniform. Biotope community definitions are usually based on species lists/turnover levels and species dominance rather than density levels. Therefore, a biotope that can occur in occasional dense patches may have average values that fall below descriptor thresholds (see Gonzalez-Mirelis et al., 2021 for an example). Consequently, information about community minimum, maximum and average densities could be useful when assessing biotope conservation-relevance further.

Biotopes as a concept are arguably still a reasonable basis for a conservation assessment, given that the ultimate goal of conservation management is the conservation of biodiversity and uniqueness in nature (Leathwick et al., 2003, Grantham et al., 2010, Mellin et al., 2011). Biotopes (individually and collectively) can act as surrogates for these features, simplifying the daunting tasks of mapping all the individual constituent species, environments, and the ecological processes (e.g., recruitment, dispersion, etc.) that underpin them (Richmond & Stevens 2014, Mellin et al., 2011). There is, however, a spectrum of effectiveness when using surrogate concepts (Richmond & Stevens 2014, Mellin et al., 2011). The biotope concept used in this case study is a hybrid, defined on the basis of biotic groupings (level 6: biological facies *sensu* Last et al. (2010)) and retained and mapped based on abiotic patterns (i.e. sometimes reduced to level 5: secondary biotopes)(Buhl-Mortensen et al. 2020). Further work could go into finding the best surrogate approach for this conservation-relevance application.

Another issue highlighted by this case study is that some criteria are much harder to assess than others and may require types of data that are not currently available. The FAO VME "Life-history traits affecting recovery", OSPAR "Sensitivity", and EBSA "Vulnerability, fragility, sensitivity, or slow recovery" criteria, for example, require species-specific information about whether biotope-associated animals are likely to recover from impact. This kind of information is hard to obtain and is often based solely on expert judgement (which is not infallible). Morato et al. (2018) have consolidated expert judgement to score the FAO VME listed taxa: a list which could be used to provide some insight for pre-listed taxa. However, adding extra taxa to Morato et al.'s (2018) list is hard to do with an opinion-based scoring approach, and using only the existing scores defeats the purpose of highlighting non-listed biotopes (with non-listed taxa) as being potentially conservation-relevant. The UK Joint Nature and Conservation Committee have commissioned work to begin a peer-reviewed database of benthic sensitivity information (MarESA, Tyler-Walters et al., 2018). To date this is focussed on regionally-relevant habitats, is still under development so is non-exhaustive, and is necessarily largely qualitative. Consequently, such databases are the starting point for evaluating these criteria, and where information is lacking, targeted biotope-specific studies will be needed to inform these assessments.

OSPAR's "Status of decline" criterion is also hard to assess without time-series monitoring data, and "Global importance" and "Regional importance" criteria require knowledge of the biotope's worldwide distribution; all of which are generally lacking due to a lack of systematic study or exploration worldwide (especially in deep water). Literature searches can be used to support all "problem" criteria, where studies do exist, but it should be assumed that this information will be lacking for most taxa (and therefore biotopes). In all cases expert knowledge should be applied, with precautionary principle as a fallback i.e. assuming highest conservation-relevance (i.e. high sensitivity to impact, high rate of decline, high regional/global importance) until evidence exists to the contrary.

Due to there being such unevaluated or partially evaluated criteria, note that the described method is not suitable for assessing whether existing listed biotopes should be downgraded. That is not what this method is designed for, and the method would not give a comprehensive evaluation. Therefore, any listed biotopes that did not qualify to be listed in Table 5 have not been discussed further.

Given all these issues, it is very important that the results of this method be subject to further evaluation. Amongst other things, consideration must be given to the resolution and quality of the input data. In this case study, the Halpern HI score and chlorophyll *a* inputs may be aggregated at a resolution coarser than that at which marine managers operate, warranting further regional analysis (Richmond & Stevens 2014, Mellin et al., 2011). Furthermore, high ranks achieved by "partial descriptors" could inappropriately weight maximum rankings. Further work could go into some form of down-weighting for partial descriptor ranks to ensure that final maximum rankings are not biased towards them, but in the meantime these need to be contextualised further before assuming conservation-relevance. The case study shows an example of the need for this verification step where, of the three biotopes highlighted as potential list candidates, only one is considered "ready" to be put forward to marine managers (biotope ZA), while two others (F and M) should be subject to further investigation before they merit such a recommendation.

5. Conclusions

This study demonstrates a quantitative method for evaluating the conservation-relevance of newly discovered biotopes. While applied to a data-rich case study, the method can be applied to any baseline dataset that can be subject to biotope-like classification and tailored to evaluate many common conservation criteria. Careful consideration must always be given to biases in the dataset, the completeness of descriptors, and the strength of the evidence base the method generates. Assuming that this care is given, this method has great potential for supplementing international lists with regionally-relevant conservation targets. Consequently, this method will now be incorporated into MAREANO procedures for the future with the aim of continually evaluating newly discovered biotopes to support marine management decision-making in Norway.

CRediT authorship contribution statement

Rebecca E. Ross: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Genoveva Gonzalez-Mirelis:** Resources, Data curation, Conceptualization, Software, Writing – review & editing. **Gunnstein Bakke:** Conceptualization, Funding acquisition, Supervision, Project administration, Writing – review & editing. **Margaret F.J. Dolan:** Resources, Formal analysis, Writing – review & editing. **Pål Buhl-Mortensen:** Supervision, Project administration, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The authors would like to thank the Norwegian government for funding this work through the MAREANO programme partners (Institute of Marine Research, Norwegian Geological Survey, and Kartverket) and the Norwegian Fisheries Directorate. Multiple personnel have been involved in collecting, processing and analysing these data since 2006, without whom this type of meta-analysis would not have been possible.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2023.109973.

References

Ayma, A., Aguzzi, J., canals, M., Lastras, G., Bahamon, N., Mecho, A., Company, J.B., 2016. Comparison between ROV video and Agassiz trawl methods for sampling deep water fauna of submarine canyons in the Northwestern Mediterranean Sea with

observations on behavioural reactions of target species. Deep Sea Research Part 1: Oceanographic Research Papers 114, 149-159.
Bellec, V.K., Bøe, R., Bjarnadóttir, L.R., Albretsen, J., Dolan, M., Chand, S., et al., 2019. Sandbanks, sandwaves and megaripples on Spitsbergenbanken, Barents Sea. Marine Geol. 416, 105998 https://doi.org/10.1016/j.margeo.2019.105998.
Buhl-Mortensen, P., Buhl-Mortensen, L., Dolan, M., Dannheim, J., Kröger, K., 2009a. Megafaunal diversity associated with marine landscapes of northern Norway: a preliminary assessment. Norw. J. Geol. 89, 163–171.
Buhl-Mortensen, L., Buhl-Mortensen, P., Dolan, M.J.F., Holte, B., 2015. The MAREANO programme –A full coverage mapping of the Norwegian off-shore benthic environment and fauna. Mar. Biol. Res. 11, 4–17.
Buhl-Mortensen, L., Buhl-Mortensen, P., 2017. Marine litter in the Nordic Seas: distribution composition and abundance. Mar. Pollut. Bull 125, 260–270. https://doi.org/10.1016/j.marpolbul.2017.08.048.
Buhl-Mortensen, P., Dolan, M., Buhl-Mortensen, L., 2009b. Prediction of benthic biotopes on a Norwegian offshore bank using a combination of multivariate analysis and GIS classification. ICES J. Mar. Sci. 66, 2026–2032.
Buhl-Mortensen, P., Dolan, M.F.J., Ross, R.E., Gonzalez-Mirelis, G., Buhl-Mortensen, L., Bjarnadóttir, L.R., Albretsen, J., 2020. Classification and Mapping of Benthic Biotopes in Arctic and Sub-Arctic Norwegian Waters. Front. Mar. Sci. 7, 271. https://doi.org/10.3389/fmars.2020.00271.
CBD CoP. 2008. Decision adopted by the conference of the parties to the convention on biological diversity at its ninth meeting IX/20 Marine and Coastal Diversity. UNEP/CBD/COP/DEC/IX/20. Available from: https://www.cbd.int/doc/decisions/cop-09/cop-09-dec-20-en.pdf (accessed 06.09.2022).
Che Hasan, R., Ierodiaconou, D., Laurenson, L., 2012. Combining angular response classification and backscatter imagery segmentation for benthic biological habitat mapping. Estuar. Coast. Shelf Sci. 97, 1–9.
Clark, M.R., Rowden, A.A., Schlacher, T.A., Guinotte, J., Dunstan, P.K., Williams, A., O`Hara, T., Watling, L., Niklitschek, E., 2014. Identifying Ecologically or Biologically Significant Areas (EBSA): A systematic method and its application to seamounts in the South Pacific Ocean. Ocean Coast. Manag. 91, 65–79.
Derous, S., Agardy, T., Hilewaert, H., Hostens, K., Jamieson, G., Lieberknecht, L., Mees, J., Moulaert, I., Olenin, S., Paelinckx, D., Rabaut, M., Rachor, E., Roff, J., Stienen, E.W.M., Van der Wal, J.T., Van Lancker, V., Verfailie, E., Vincx, M., Węsławski, J.M., Degraer, S., 2007. A concept for biological valuation in the marine environment. Oceanologia 49, 99–128.
Dolan, M.F.J., Buhl-Mortensen, P., Thorsnes, T., Buhl-Mortensen, L., Bellec, V.K., Bøe, R., 2009. Developing seabed nature-type maps offshore Norway: initial results from the MAREANO programme. Norw. J. Geol. 89, 17–28.
Dolan, M.F.J., Ross, R.E., Albretsen, J., Skarðhamar, J., Gonzalez-Mirelis, G., Bellec, V., Buhl-Mortensen, P., Bjarnadóttir, L.R., 2021. Using Spatial Validity and Uncertainty Metrics to Determine the Relative Suitability of Alternative Suites of Oceanographic Data for Seabed Biotope Prediction. A Case Study from the Barents Sea, Norway. Geosciences 11, 48. https://doi.org/10.3390/geosciences11020048.
Durden, J.M., Schoening, T., Althaus, F., Friedman, A., Farcia, R., Glover, A.G., Greinert, J., Jacobse Stout, N., Jones, D.O.B., Jordt, A., Kaeli, F.W., Köser, K., Kuhnz, L.A., Lindsay, D., Morris, K.J., Nattkemper, T.W., Osterloff, J., Ruhl, H.A., Singh, H., Tran, M., Bett, B.J., 2016. Perspectives in visual imaging for marine biology and ecology: from acquisition to understanding. Oceanogr. Mar. Biol. Annu. Rev. 54, 1–72. https://doi.org/10.1201/9781315368597.
Edgar, G.J., Bates, A.E., Bird, T.J., Jones, A.H., Kininmouth, S., Stuart-Smith, R.D., Webb, T.J., 2016. New Approaches to Marine Conservation Through the Scaling Up of Ecological Data. Ann. Rev. Mar. Sci. 8, 435–461. https://doi.org/10.1146/annurev-marine-122414-033921.
Elvenes, S., Dolan, M.F.J., Buhl-Mortensen, P., Bellec, V., 2013. An evaluation of compiled single-beam bathymetry data as a basis for regional sediment and biotope mapping. ICES J. Mar. Sci. 71, 867–881.
FAO. 2009. International Guidelines for the Management of Deep-sea Fisheries in the High Seas. Rome: FAO. 73p Available from: http://www.fao.org/documents/card/en/c/b02fc35e-a0c4-545a-86fb-4fc340e13b52 (accessed 06.09.2022).
FGDC (Federal Geographic Data Committee) 2012. FGDC-STD-018-2012: Coastal and marine ecological classification standard. FGDC, Reston, VA. Available from: https://www.fgdc.gov/standards/projects/cmecs-folder/CMECS_Version_06-2012_FINAL.pdf (Accessed 06.09.2022).
Galparsoro, I., Connor, D.W., Borja, A., Aish, A., Amorim, P., Bajjouk, T., Chambers, C., Coggan, R., Dirberg, G., Ellwood, H., et al., 2012. Using EUNIS habitat classification for benthic mapping in European seas: Present concerns and future needs. Mar. Pollut. Bull. 64, 2630–2638.
Garcia, S.M., Rice, J., Charles, A. (Eds.), 2014. Governance of Marine Fisheries and Biodiversity Conservation: Interaction and Coevolution. John Wiley & Sons, Chichester.
Gonzalez-Mirelis, G., Lindegarth, M., 2012. Predicting the distribution of out-of-reach biotopes with decision trees in a Swedish marine protected area. Ecol. Appl. 22, 2248–2264.
Gonzalez-Mirelis, G., Ross, R.E., Albretsen, J., Buhl-Mortensen, P., 2021. Modeling the Distribution of Habitat-Forming, Deep-Sea Sponges in the Barents Sea: The Value of Data. Front. Mar. Sci. 7, 496688 https://doi.org/10.3389/fmars.2020.496688.
Grantham, H.S., Pressey, R.L., Wells, J.A., Beattie, A.J., 2010. Effectiveness of Biodiversity Surrogates for Conservation Planning: Different Measures of Effectiveness Generate a Kaleidoscope of Variation. PLoS One 5 (7), e11430.
Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R., Watson, R., 2008. A Global Map of Human Impact on Marine Ecosystems Science 319, 948-952.
Halvorsen, R., Skarpaas, O., Bryn, A., Bratli, H., Erikstad, L., Simensen, T., Lieungh, E., 2020. Towards a systematics of ecodiversity: The EcoSyst framework. Glob. Ecol. Biogeogr. 29, 1887–1906.
Howell, K.L., Davies, J.S., Narayanaswamy, B.E., 2010. Identifying deep-sea megafaunal epibenthic assemblages for use in habitat mapping and marine protected area network design. J. Marine Biol. Assoc. UK 90, 33–68.
ICES, 2013. Report of the ICES\NAFO Joint Working Group on Deep-water Ecology (WGDEC), 11–15 March 2013, Floedevigen, Norway. ICES CM 2013/ACOM:28. 95 pp.
ICES, 2020. ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC). ICES Scientific Reports. 2:62. 188 pp. Available from doi:10.17895/ices.pub.7503 (accessed 06.09.2022).
Jac, C., Desroy, N., Duchêne, J.-C., Foveau, A., Labrune, C., Lescure, L., Vaz, S., 2021. Assessing the impact of trawling on benthic megafauna: comparative study of video surveys vs. scientific trawling. ICES J. Mar. Sci. 78, 1636–1649. https://doi.org/10.1093/icesjms/fsab033.
Johnson, D.E., Barrio Froján, C., Turner, P.J., Weaver, P., Gunn, V., Dunn, D.C., Halpin, P., Bax, N.J., Dunstan, P.K., 2018. Reviewing the EBSA process: Improving on success. Mar. Policy 88, 75–85. https://doi.org/10.1016/j.marpol.2017.11.014.
Last, P.R., Lyne, V.D., Williams, A., Davies, C.R., Butler, A.J., Yearsley, G.K., 2010. A hierarchical framework for classifying seabed biodiversity with application to planning and managing Australia's marine biological resources. Biol. Conserv. 143, 1675–1686. https://doi.org/10.1016/j.biocon.2010.04.008.
Leathwick, J.R., Overton, J.M., McLeod, M., 2003. An environmental domain classification of New Zealand and its use as a tool for biodiversity management. Conserv. Biol. 17, 1612–1623.
Lindal Jørgensen, L., Planque, B., Thangstad, T.H., Certain, G., 2016. Vulnerability of megabenthic species to trawling in the Barents Sea, ICES Journal of Marine Science, 73(suppl_1), Pages i84–i97. doi: 10.1093/icesjms/fsv107.
Long, S., Sparrow-Scinocca, B., Blicher, M.E., Hammeken Arboe, N., Fuhrmann, M., Kemp, K.M., Nygaard, R., Zinglersen, K., Yesson, C., 2020. Identification of a Soft Coral Garden Candidate Vulnerable Marine Ecosystem (VME) Using Video Imagery, Davis Strait, West Greenland. Front. Mar. Sci. 7, 460. https://doi.org/10.3389/fmars.2020.00460.
McConnaughey, R.A., Mier, K.L., Dew, C.B., 2000. An examination of chronic trawling effects on soft-bottom benthos of the eastern Bering Sea. ICES J. Mar. Sci. 57, 1377–1388.
Mellin, C., Delean, S., Caley, J., Edgar, G., Meekan, M., et al., 2011. Effectiveness of Biological Surrogates for Predicting Patterns of Marine Biodiversity: A Global Meta-Analysis. PLoS One 6 (6), e20141.
Morato, T., Pham, C.K., Pinto, C., Golding, N., Ardron, J.A., Muñoz, P.D., Neat, F., 2018. A Multi Criteria Assessment Method for Identifying Vulnerable Marine Ecosystems in the North-East Atlantic. Front. Mar. Sci. 5, 460. https://doi.org/10.3389/fmars.2018.00460.
Murillo, F.J., Serrano, A., Kenchington, E., Mora, J., 2016. Epibenthic assemblages of the Tail of the Grand Bank and Flemish Cap (northwest Atlantic) in relation to environmental parameters and trawling intensity. Deep Sea Res. Part I 109, 99–122. https://doi.org/10.1016/j.dsr.2015.08.006.
Olenin, S., Ducrotoy, J.-P., 2006. The concept of biotope in marine ecology and coastal management. Mar. Pollut. Bull. 53, 20–29. https://doi.org/10.1016/j.marpolbul.2006.01.003.
OSPAR. 2019. Criteria for the Identification of Species and Habitats in need of Protection and their Method of Application (The Texel-Faial Criteria). OSPAR Agreement 2019-03 (replacing OSPAR Agreement 2003-13). Available from: https://www.ospar.org/documents?v=40948 (accessed 06.09.2022).
OSPAR. 2008. OSPAR List of Threatened and/or Declining Species and Habitats. OSPAR Agreement 2008-6. Available from: https://www.ospar.org/documents?d=32794 (accessed 06.09.2022).
Piechaud, N., Downie, A., Stewart, H.A., Howell, K.L., 2015. The impact of modelling method selection on predicted extent and distribution of deep-sea benthic assemblages. Earth Environ. Sci. Trans. R. Soc. Edinb. 105, 251–261.
Porskamp, P., Rattray, A., Young, M., Ierodiaconou, D., 2018. Multiscale and hierarchical classification for benthic habitat mapping. Geosciences 8, 119.
Richmond, S., Stevens, T., 2014. Classifying benthic biotopes on sub-tropical continental shelf reefs: How useful are abiotic surrogates? Estuar. Coast. Shelf Sci. 138, 79–89. https://doi.org/10.1016/j.ecss.2013.12.012.
Robinson, K.A., Ramsay, K., Lindenbaum, C., Frost, N., Moore, J., Wright, A.P., Petrey, D., 2011. Predicting the distribution of seabed biotopes in the southern Irish Sea. Continental Shelf Res. 31, S120–S131.
Schiele, K.S., Darr, A., Zettler, M.L., Friedland, R., Tauber, F., von Weber, M., Voss, J., 2015. Biotope map of the German Baltic sea. Mar. Pollut. Bull. 96, 127–135.
Tyler-Walters, H., Tillin, H.M., d'Avack, E.A.S., Perry, F., Stamp, T., 2018. Marine Evidence-based Sensitivity Assessment (MarESA) – A Guide. Marine Life Information Network (MarLIN). Marine Biological Association of the UK, Plymouth, pp. 91. Available from: https://www.marlin.ac.uk/publications (accessed 08.11.2022).
Watling, L., Auster, P.J., 2017. Seamounts on the High Seas Should Be Managed as Vulnerable Marine Ecosystems. Front. Mar. Sci. 4, 14. https://doi.org/10.3389/fmars.2017.00014.
Williams, A., Althaus, F., Schlacher, T.A., 2015. Towed camera imagery and benthic sled catches provide different views of seamount benthic diversity. Limnol. Oceanogr. Methods 13, 62–73.
Yamakita, T., Sudo, K., Jintsu-Uchifune, Y., Yamamoto, H., Shirayama, Y., 2017. Identification of important marine areas using ecologically or biologically significant areas (EBSAs) criteria in the East to Southeast Asia region and comparison with existing registered areas for the purpose of conservation. Mar. Policy 81, 273–284.