Vulnerable biodiversity below the surface

The diversity of life in the sea is critical to the health of ocean ecosystems that support living resources and therefore essential to the economic, nutritional, recreational, and health needs of billions of people. Yet there is evidence that the biodiversity of many marine habitats is being altered in response to a changing climate and human activity. Understanding this change, and forecasting where changes are likely to occur, requires monitoring of organism diversity, distribution, abundance, and health [1].

Large-scale, long-term management is important because biodiversity is a global concern, and organisms do not respect national boundaries. An internationally accepted way of doing this is by Marine protected areas (MPA). It is the obvious way of reaching the 10% conservation goal found in Sustainable Development Goal 14 (which is part of the Convention on Biological Diversity). Categories of protection are already developed and in use: IUCN protected area categories, or IUCN protected area management categories, are categories used to classify protected areas in a system developed by the International Union for the Conservation of Nature (IUCN). An important part of these areas are benthic organisms and human impact on them. The term Vulnerable Marine Ecosystems (VME) is used to describe vulnerable ecosystems based on benthic sedentary organisms. By defining VMEs it is possible to point to the most vulnerable marine ecosystems. This suggestion is aimed at filling some of the data gaps that exist and at the same time aid in fulfilling Denmark's international obligations. This paper concentrates on the VME part of the marine ecosystems, the part most in need of protection.

Background

Vulnerable Marine Ecosystems. The term is relatively new and was widely noticed by the North Atlantic international management and political system in 2008 [3–5]. This year marks the first year where the term was widely discussed in North Atlantic Fisheries Organisation (NAFO), the Regional Fisheries Management Organisation (RFMO) governing international waters in the North West Atlantic. The meeting in 2008 marked a noticeable change in governance perspective. From a fisheries oriented organisation to an organisation where bycatch like corals and sponges suddenly took centre stage. The ad hoc Fisheries Commission Working Group of Fishery Managers and Scientists (FCWG FMS-VME) was established in 2008 to tackle the problem from several angles.

From NAFO the discussion trickled to North-East Atlantic Fisheries Commission (NEAFC) and other RFMOs [6].

Obviously, the discussion was older, and had been going on for years amongst e.g. scientists, the Green organisations, and the UN system [6–8]. The United Nations General Assembly Resolution 61/105 from 2006 calls upon 'States to take action immediately, individually and through Regional Fisheries Management Organizations and arrangements, and consistent with the precautionary approach and ecosystem approaches, to sustainably manage fish stocks and protect vulnerable marine ecosystems… from destructive fishing practices, recognizing the immense importance and value of deep sea ecosystems and the biodiversity they contain'. It was this resolution that was invoked when taking action in NAFO in 2008; it was followed by UN resolution 64/72 and the International Guidelines for the Management of Deep-sea Fisheries in the High Seas (hereafter the Guidelines) [9]. A number of relevant regulations can be found in the appendix.

A few key ecosystems are mentioned in the Guidelines while others must be defined by criteria listed in the Guidelines [9]. The main interest in the international discussions have been the definition of VMEs and the organisms that should be defined as VMEOs [2,7,10,11]. Identification of specific areas is an ongoing process in the wider North Atlantic (and beyond) both in international waters and national waters. An overview of VMEs in the high seas can be found in the FAO database http://www.fao.org/in-action/vulnerable-marine-ecosystems/vme-database/en/vme.html . VMEs will differ from ecoregion based on species composition in the specific area. I have developed a transparent point system based on the Guidelines and developed and an error score system was developed to highlight gaps in knowledge.

Defining a VME

A first step in identifying VMEs is the identification of possible Vulnerable Marine Ecosystem Organisms (VMEO). When defining VMEs it is important to use a regional setting as some organisms can be rarer in local settings than the wider Atlantic and some types of VMEs will not be found in Denmark at all. The preliminary work can be done as a literature study combined with expert knowledge e.g. threats. A new approach in evaluating VMEOs with a transparent weighting system and error score system is incorporated here. **Part of this system has already been incorporated by ICES in their VME portal.** By analysing the species (taxa) and identifying the ones that have the highest scores it is possible to focus the effort on relevant features. Important parts of this evaluation approach has been incorporated in the 'weighting system' that is part of the VME work of the ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC) [2]. Adding an error score or uncertainty in the reported measurement for each organism is novel and introduces an opportunity to see which organisms are least studied. With the introduction of the VME weighting and error score system it is possible to plan where to focus future management and scientists to plan where to focus future work

Despite this growing interest few studies have taken place. Here I introduce a weighting system of VME organisms and an error score of uncertainty applied to identify areas where knowledge is most limited.

VME indicators based on the FAO Guidelines

A marine ecosystem should be classified as vulnerable based on the characteristics that it possesses and then an evaluation has to take place deciding if it is a VME [9]. The guidelines also provide examples of species groups, communities and habitat-forming species which may contribute to forming vulnerable marine ecosystems. These traits can be applied to VMEs as structures dominated by one species or multiple species alike. The traits from the Guidelines are listed below

- Uniqueness or rarity
- Functional significance of the habitat
- Fragility
- Life-history traits that make recovery difficult
    - Slow growth rates
    - Late age of maturity
    - Low or unpredictable recruitment
    - Long lived
- Structural complexity

The following examples of species groups, communities, habitats and features are mentioned in the Guidelines as possible VMEs. All the mentioned groups will be evaluated along with a few other taxa.

1) Certain coldwater corals and hydroids, e.g. reef builders and coral forests including
    - Stony corals (Scleractinia)
    - Soft corals (Alcyonaceans)
    - Gorgonians (Octocorallia)
    - Black corals (Antipatharia)
    - Hydrocorals (Stylasteridae)
2) Some types of sponge dominated communities

3) 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.
4) Seep and vent communities comprised of invertebrate and microbial species found nowhere else (i.e. endemic).

The following topographical, hydrophysical or geological features are mentioned in the Guidelines that might support the above mentioned species groups. Not all features are relevant in a Danish context.

1) Submerged edges and slopes (e.g. corals and sponges)
2) Summits and flanks of seamounts, guyots, banks, knolls, and hills (e.g. corals, sponges, xenophyophores)
3) Canyons and trenches (e.g. burrowed clay outcrops, corals)
4) Hydrothermal vents (e.g microbial communities and endemic invertebrates)
5) Cold seeps (e.g. mud volcanoes for microbes, hard substrates for sessile invertebrates)

As the name implies a VME is vulnerable to specific forms of action. Vulnerability is defined by FAO (2009) and is related to the likelihood that a population, community or habitat will experience substantial alternation from short-term or chronic disturbance; the likelihood that it would recover and in what time frame. VMEs features might be physically or functionally fragile, the most vulnerable are those that are both easily disturbed and very slow to recover or may never recover [9]. The UNGA resolution explicitly refers to interactions that cause significant adverse impacts. This is defined as 'experiencing substantial alteration from short-term or chronic disturbance, and the likelihood that it would recover and in what time frame'.

The concept of Significant Adverse Impacts (SAI) as described in the Guidelines is an important component of the management of VMEs. SAIs are considered those impacts that compromise ecosystem integrity (i.e. ecosystem structure or function) in a manner that:

- Impairs the ability of the affected populations to replace themselves
- Degrades the long-term natural productivity of habitats
- Causes, on a more than a temporary basis, significant loss of species richness, habitat or community types.

When determining the scale and significance of an impact it is important to consider a number of factors including specific threats, including the type of fishing gear used to create the impact. SAIs can be split into impacts directly on the organisms affected and wider effects including recoverability, spatial extent, ecosystem alterations and timing and duration of impact. The Guidelines defines temporary impacts as those that are limited in duration and that allow the particular ecosystem to recover over an acceptable time frame. These must be addressed on a case-by-case basis and should be in the order of 5-20 years, taking into account the frequency of the disturbance. If the interval between the disturbances are shorter than the recovery time, the impact should be considered more than temporary [9]. Threats to sessile organisms are well known but should be evaluated for each group and spatial location.

Evaluating VME organisms

A wide range of organisms have been evaluated based on the Guidelines and each organism/group considered as relevant for VMEO. The organisms shown here are known to occur in Greenland as the system was developed for testing in Greenland waters. The method was developed for my PhD thesis and is applicable for use all over the world.

Table 1. Criteria for evaluating organisms. Criteria (grey) and categories (white) are taken from the FAO guidelines. The score is divided into a green, yellow and red category. Red reflects the most vulnerable/rare/old category and is a visual aid when using the scoring system. Each organism is given one score for each of the categories. When summed the score can be transferred to an error bar chart reflecting the score or uncertainty.

Criteria	Categori	Score		
Uniqueness/rarity North Atlantic	Redlisted	not redlisted 1	3	redlisted 5
	Endemic	non endemic 1	3	endemic 5
	Rare	non rare 1	3	rare 5
	Threatned	not threatened 1	3	threatened 5
Uniqueness/rarity Greenland	Redlisted	not redlisted 1	3	redlisted 5
	Endemic	non endemic 1	3	endemic 5
	Rare	non rare 1	3	rare 5
	Threatned	not threatened 1	3	threatened 5
Ecosystem function Greenl	N/F/B/S areas	not N/F/B/S areas 1	3	N/F/B/S areas 5
	N/F/B/S areas for fish	not N/F/B/S areas for fish 1	3	N/F/B/S areas for fish 5
Fragility	Fragility/brittleness	low 1	medium 3	high 5
	Hight off bottom	value in dm	value in dm	value in dm*
	Retractability	yes 1	3	no 5
Life history traits	Lifespan	< 5 years 1	5-20 years 3	> 20 years 9
	Recruitement	regular 1	unknown 3	irregular 5
	fecundity	high 1	unknown 3	low 5
	Growthrate	fast 1	medium/unknown 3	slow 5
	Maturation age	low 1	medium/unknown 3	high 5
	recoverability	high 1	unknown 3	low 5
Structural complexity	Framebuilding	not framebuilding 1		Framebuilding 5
	Structural engineer	non structural engineer 1	Microhabitat 3	structural engineer 9
	associated species	No known associated sp 1	unknown 3	Associated species 5

Ecosystems are made of organisms; therefore the first step in identifying a VME is to identify possible VMEOs. A transparent point system based on the Guidelines has been developed; against which specific organisms can be measured (Table 1).

The left hand column 'Criteria' (grey colour) refers directly to the criteria mentioned in the Guidelines. The next column named 'Category' (white colour) splits the criteria into measurable entities (explained in detail below). The category Uniqueness/rarity (first and second vertical category) was evaluated for the wider North Atlantic and for the West coast of Greenland separately. This distinction was made because some organisms e.g. *Primnoa resedaeformis* seems to be more common in the wider North Atlantic than in Greenland [12]. The score is evaluated as a three tired stoplight scoring system: Green is low score, low impact. Yellow is middle score, middle impact or unknown impact. Red is high score, rare or high impact. To embrace the precautionary approach an error is introduced as one error point when the score is yellow/'unknown'; an example is given below (Figure 1).

Criteria	Categori	Score			Boltenia c	error
Uniqueness/rarity North Atlantic	Redlisted	not redlisted 1	3	redlisted 5	1	
	Endemic	non endemic 1	3	endemic 5	1	
	Rare	non rare 1	3	rare 5	1	
	Threatned	not threatened 1	3	threatened 5	1	
Uniqueness/rarity Greenland	Redlisted	not redlisted 1	3	redlisted 5	1	
	Endemic	non endemic 1	3	endemic 5	1	
	Rare	non rare 1	3	rare 5	1	
	Threatned	not threatened 1	3	threatened 5	1	
Ecosystem function Greenland	N/F/B/S areas	not N/F/B/S areas 1	3	N/F/B/S areas 5	3	1
	N/F/B/S areas for fish	not N/F/B/S areas for fish 1	3	N/F/B/S areas for fish 5	3	1
Fragility	Fragility/brittleness	low 1	medium 3	high 5	3	
	Hight off bottom	value in dm	value in dm	value in dm*	5	
	Retractability	yes 1	3	no 5	5	
Life history traits	Lifespan	< 5 years 1	5-20 years 3	> 20 years 5	3	1
	Recruitement	regular 1	unknown 3	irregular 5	3	1
	fecundity	high 1	unknown 3	low 5	3	1
	Growthrate	fast 1	medium/unknown 3	slow 5	3	
	Maturation age	low 1	medium/unknown 3	high 5	3	1
	recoverability	high 1	unknown 3	low 5	3	1
	Framebuilding	not framebuilding		Framebuilding		

Figure 1. Shows the weighting system and how error is introduced in the system. *Boltenia ovifera* is used as an example. An error (ringed in red) is introduced as one error point when the score is yellow/'unknown'. Adding these errors will produce an error score that can be used as a visualisation of the little known factors for *B. ovifera*. In this example, little is known about e.g. lifespan, recruitment and fecundity.

Some organisms have two distinct growth forms. They have been considered twice, once for each growth form. This relates e.g. to the stone coral *L. pertusa* (reef and colony). This approach is in line with the classification scheme of European cold-water coral habitats [13].

This approach result in an error score or uncertainty in the reported measurement for each organism, representing lack of knowledge (Figure 2). The error score can be visualized with error bars and gives a visual guide to areas where data is missing. **This approach offers an easy overview of data gaps and is well suited for management purposes.**

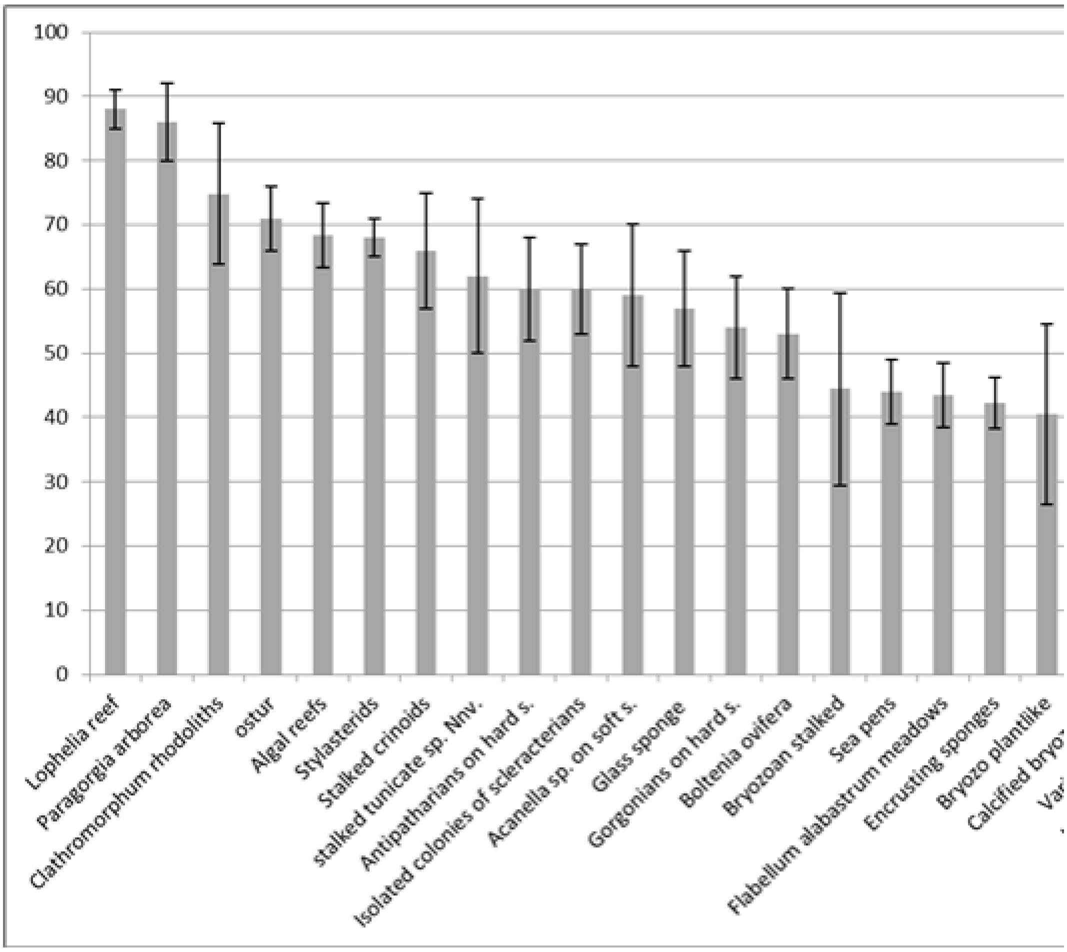

Figure 2. Illustrations of the weighting system from Fig. 1 with error bars. The error score is a visualisation of 'unknown factors'. For each criteria in the yellow category an error of 1 is introduced (e.g. recruitment unknown), adding these errors gives a visualisation of unknown factors for the organism in question. This example is from Greenland waters.

Appendix A: Some regulations and agencies of relevance

Sources of International law

- **UN**
    - Law of the Sea (1982)
      General wording – no mentioning of VME
    - UN Fish Stocks Agreement (1995)
      General wording – no mentioning of VME

    - UNGA RES 59/25 (2004)
    - UNGA RES 61/105 (2006)
    - UNGA RES 64/72 (2009)
    - UNGA RES 66/68 (2011)

    - FAO Code of Conduct (1995)
    - FAO Deep-Sea Fisheries Guidelines (2008)
    - FAO Implementation of the Deep sea Guidelines (2010)
- **IMO**
  General wording – no mentioning of VME

EU law and domestic laws and regulations

RFMOs which manage fish stocks by geographical area

- NAFO (Nortwest Atlantic Fisheries Organisation)
- NEAFC (North-East Atlantic Fisheries Comission)
- SIOFA (South Indian Ocean Fisheries Agreement)
- SEAFO (South-East Atlantic Fisheries Organisation)
- SPRFMO (South Pacific Regional Fisheries Management Organisation)
- CCAMLR (Convention on Conservation of Antarctic Marine Living Resources
- GFCM (General Fisheries Comission for the Mediterranean)

Other organisations

- Convention on Biological Diversity
    - Ecologically or biologically significant marine areas (EBSAs)
- OSPAR
    - Marine protected areas
- EU Fisheries policy
- ICES

Litterature

1. Canonico, G. *et al.* Global Observational Needs and Resources for Marine Biodiversity. *Front. Mar. Sci.* **6**, 367 (2019).

2. ICES. *Report of the ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC), 24–28 February 2014, Copenhagen, Denmark.* (2014).

3. NAFO. Part A: Scientific Council Meeting, 5-19 JUNE 2008. *SC* **SC 5**, 1–222 (2008).

4. NAFO. Delineation of Existing Bottom Fishing Areas in the NAFO Regulatory Area. *NAFO SCS Doc. 09/21* (2009).

5. WGFMS. Report of the Ad Hoc Working Group of Fishery Managers and Scientists on Vulnerable Marine Ecosystems (WGFMS) 8 – 12 September 2008 Montreal, Canada. *NAFO* 1–28 (2008).

6. Freiwald, A., Fosså, J. H., Grehan, A., Koslow, T. & Roberts, J. M. Cold Water Coral Reefs out of sight - no longer out of mind. *Biodivers. Ser. 22* 1–84 (2004).

7. Rogers, A. D. & Gianni, M. *The Implementation of UNGA Resolutions 61/105 and 64/72 in the Management of Deep-Sea Fisheries on the High Seas. A report from the International Programme on the State of the Ocean*. (2010).

8. UNGA. *61/105 Sustainable fisheries, including through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks an*. (2006).

9. FAO. *The FAO international guidelines for the management of deep-sea fisheries in the high seas*. (2009).

10. NAFO. *Report of the ad hoc Working Group of Fishery Managers and Scientists (WGFMS) 8-12 September 2008 Montreal, Canada. FC Doc. 08/8 Serial No. N5564*. (2008).

11. NAFO. *Report of the working group on the Ecosystem Approach to Fisheries Management (WGEAFM) NAFO SCS Doc. 09/6. Serial No. N5627*. (2009).

12. Buhl-Mortensen, L., Olafsdottir, S. H., Buhl-Mortensen, P., Burgos, J. M. & Ragnarsson, S. A. Distribution of nine cold-water coral species (Scleractinia and Gorgonacea) in the cold temperate North Atlantic: effects of bathymetry and hydrography. *Hydrobiologia* **759**, 39–61 (2015).

13. Davies, J. S. *et al.* A new classification scheme of European cold-water coral habitats: Implications for ecosystem-based management of the deep sea. *Deep Sea Res. Part II Top. Stud. Oceanogr.* **145**, 102–109 (2017).