Theme session O

Vulnerable marine ecosystems (VMEs): key structural and functional elements in the deep-sea

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Vulnerable Marine Ecosystem (VMEs) are some of the world's most diverse and ecologically important deep-sea ecosystems; they provide habitat, refuge, and nursery areas for multiple associated species. The term, used for the first time in UN General Assembly Resolution 61/105 in 2004, is now widely used by scientists, managers, and policy makers. VMEs are extremely vulnerable to anthropogenic disturbance, and frequently occur in areas of intense fishing activity. Ongoing and emerging threats for these ecosystems include oil and gas exploration and extraction, as well as deep-sea mining. Industries, managers, and scientists need to balance the fragile equilibrium between the conservation of VMEs and the sustainable use of marine resources.

During the last two decades, studies on cold-water coral (CWC) reefs, sponge fields, hydrothermal vents, and other VMEs have increased worldwide; for example in mapping their occurrence or developing knowledge of their biology and physiological responses. VME science is still in its infancy, however, and many aspects haven´t been addressed yet. This session aimed to highlight the current studies on VMEs, identifying key gaps in knowledge and the ongoing science, including new discovery and proposals of VMEs; application of new technologies and methodologies to detect, map, define, and assess impacts on VMEs.

A good number of contributions were submitted for the session; the allocated time allowed the acceptance of 10 oral presentations and 6 posters, with the participation of some early career scientists. The selection of contributions covered a large latitudinal gradient, as well as many topics (e.g. community characterization, new discoveries, genetics, databases and definitions, management, fishing impact, modelling, etc.) related to research on VMEs and deep-sea benthic ecosystems in general. Around 70 delegates attended the session, contributing to interesting and vivid discussions after the presentations and at the end of the session.

1. New discoveries and proposals for VMEs: Research on VMEs and deep-sea ecosystems

New discoveries of deep-sea communities, including VMEs, have been made using a range of survey methods (most of them visual methods; see section 3 of this report) across the globe, from the Arctic through the North Atlantic to the Mediterranean, and across to the South Atlantic and wider Pacific Ocean. Buhl-Mortensen et al. highlighted widespread and diverse VME communities from Norway, found through the MAREANO project, further illustrated by Ross et al. Additional VME data across the Arctic and sub-Arctic was shown from the NOVASARC project, where 40,000 VME records comprising of corals and sponges were collated from national surveys by the Faroe Islands, Iceland,

and Norway (Buhl-Mortensen et al.). Long et al. also illustrated the presence of a range of VME communities in Greenlandic waters, including soft coral gardens of *Nephtid* spp. and fields of *Anthomastus* spp., around fishing grounds where no VMEs were present. Robson et al. presented the ICES VME database, containing > 40,000 records of VME indicators and habitats from the North Atlantic, also referring to the issue of "when a VME indicator becomes a VME habitat" (see section 2 of this report). From the Mediterranean, Costantini et al. showed examples of seamounts and canyons with species of the black coral, *Antipathella subpinnata* and the importance of connectivity studies for management and conservation purposes. Mytilineou et al. and Smith et al. detailed VMEs from seamounts, mud volcanoes, and canyons across the Eastern Mediterranean collated by the DEEPEASTMED project. These studies also highlighted the importance of VMEs as a habitat for many other species and associated fauna, including vulnerable species such as deep-sea sharks. Along similar lines, Chimienti et al. provided data on the occurrence and ecological role of a species of bamboo coral, *Isidella elongata,* in the Mediterranean, as well as the current vulnerability of this critically endangered species.

Furthermore, VME mapping in the South Atlantic was presented by Franken et al., where VMEs, including sponges, sea-pens, and lace corals, have been more recently (< 10 years ago) identified within the EEZs of South Africa and the Prince Edward Islands. This study also remarked on the important achievement of the declaration of 20 MPAs (some in deep waters off South Africa), 10 of which host VME indicator species. In comparison, data collection from the South Pacific is more advanced with large glass sponge reefs in the Salish Sea being identified, as shown by Dunham et al. This work pointed out the fundamental ecological role of sponges in carbon flux and carbon sequestration, displaying values similar to terrestrial forests. Also from the Southern hemisphere, Rowden et al. and Geange et al. presented data on deep-water VMEs such as coral reefs in the South Pacific and they noted the importance of moving towards functional roles and significance when defining VMEs, besides biomass and density values (see section 2).

2. Revisiting guidelines, measures, and thresholds to define and quantify VMEs

As already mentioned in the previous section, one of the challenges many presenters raised was how to best define VMEs, following the Food and Agriculture Organisation (FAO) of the United Nations' criteria. This was particularly recognised as an issue in terms of fisheries management for the protection of VMEs.

The analyses of records from the NOVASARC project conducted by Buhl-Mortensen et al. enabled a clear breakdown of VME habitat types following the FAO criteria, and the authors defined a list of VME habitats for Norway, suggesting these criteria are beneficial in VME identification. However, they also indicated that deciding whether areas of scattered deep-sea communities were considered a 'VME' led to challenges for those involved in management. Long et al. raised further issues about use of the FAO criteria, e.g. 'uniqueness/rarity', 'functional significance', and 'structurally complex', when determining VME presence, particularly concerning questions of what makes a 'significant concentration' of VME indicators. This question of 'significant concentration' was also discussed by Rowden et al. in terms of how to determine density thresholds as reference points for VME indicators and VME habitats to support spatial management measures (see section 3).

To address issues around VME definitions, Robson et al. highlighted work undertaken through the Joint ICES/NAFO Working Group on Deep-water Ecology (WGDEC) to develop a multi-criteria assessment method to rank the vulnerability of VME indicators and abundance, and illustrate areas of high, medium and low 'VME likelihood'. However, these methods still have limitations, including how to best rank vulnerability of indicators. These authors also suggested that alternative methods used by Canada reviewing 'Kernel Density Estimation' (KDE) could be considered further. As pointed out by Costantini et al. and Rowden et al., other connectivity and functionality criteria such as genetic diversity, isolation or structural complexity might help to develop clearer and robust criteria to define VMEs. Indeed, larval connectivity and genetic diversity/structure have been highlighted as gaps in the VME FAO criteria. These should be taken into account, in parallel with the advances gained in these research fields.

3. New tools: techniques, technologies, and modelling to investigate VMEs and impacts on VMEs

Most studies conducted on VMEs take place through the application of so-called 'non-invasive methods', which mostly include Remotely Operated Vehicles (ROVs), manned submersibles, or underwater cameras. Field work methodologies, as well as new methods and techniques for data analyses to support improvements to, or implementation of new, management measures to protect VMEs from impacts, were discussed in a number of presentations.

The work presented by Long et al. shows how an unsophisticated drop-camera can provide novel and valuable information on the occurrence and extent of VME habitats. Regarding advances in data analyses, Rowden et al. presented methods to model VME thresholds, suggesting that the relationship between density/abundance of VME and associated diversity could be used to help define a threshold for the 'structural complexity' FAO criteria, with results showing a threshold of 30% live and dead coral cover. Again, however, limitations must be considered; there are few VME data available for analysis and there are wide confidence intervals. Work on modelling thresholds was also shown by Geange et al., who identified these tools as a method to support managers in preventing 'Significant Adverse Impacts' (SAIs) to VMEs. Thresholds were identified from these models that could be proposed for use as move-on rule thresholds, to complement spatial management measures. Confidence in the models, however, must be considered carefully.

Other methods to support managers in prevention of SAIs on VMEs were shown by Durán-Muñoz et al. for the Flemish Cap and Flemish Pass (Northwest Atlantic), where mapping tools have been used to evaluate the overlap of VME data with data on deep-sea fisheries and other stressors, to identify conflict zones and explore options for Marine Spatial Planning (MSP). As further described by Ross et al. the presence of VME indicator species over extended areas, such as in the Norway shelf, might not help to guide management. Here, the identification of hot-spots for conservation actions might be a compromise solution. These hot-spot approaches could be really valuable for protection of VMEs, especially in areas where impacts on VMEs are very prominent, as is the case in the Mediterranean for *Isidella elongata* aggregations; the *Isidella* populations have dramatically decreased from trawling pressure, as shown by Chimienti et al. Another very interesting approach was presented by Costantini et al. who described a study of the genetic variability of black coral species populations, and how fundamental this evidence is to management, through determining the connectivity of seamount and deep coastal populations in the Mediterranean. These authors provided scientific evidence of population distribution to support management decisions for protection.

Even though the effects of bottom trawling, as well other bottom contact gears, on VMEs have been analysed for around two decades, the number of quantitative studies is still not that large and they only cover some specific locations. On this topic, Keesing et al. showed that marine protection on Australia's NW Shelf, in an area which had historically been subjected to extensive trawling, did not improve densities of habitat-forming filter feeders 35 years after the closure of the area to trawling. Data from 2017 in a Marine Park that has been closed to trawling since 1985 showed lower biomass of filter feeders and fish (linked to the lower filter feeder biomass) than an area open to trawling. The reasons for this trend were unclear. In addition, the overall biomass of biota in the Marine Park was higher ten years prior, just after the trawl ban, with a higher proportion of sponges, than in 2017. These results seem to illustrate different recovery dynamics in the two compared areas, but also highlighted potentially inadequate sampling due to the patchiness in the area, as well as a need to better understand life-history traits of the species and basic biological aspects (such as growth rates) to apply the appropriate protection measures for each specific case.

4. Outcomes and recommendations

The contributions to the VME session displayed the **variation in the current state of knowledge, as well as the volume of data and records of VME occurrence across a latitudinal gradient in the Atlantic (including the Mediterranean) and the South Pacific**. The high densities of some VMEs documented in Norway led to the exploration of methods to detect hotspots of the most 'special places' to support marine managers in VME protection (Ross et al.). Western Canada and the US have substantial datasets on glass sponge reefs, which are now protected within bottom-fishing closure areas (Dunham et al.). In contrast, knowledge on VMEs from South Africa is in the early stages of data collection, with much of these data not yet quantified (Franken et al.). Regarding the deep-sea of the Eastern Mediterranean, this region is still poorly understood, with no systematic mapping having taken place (Smith et al.).

A complete lack of data from some areas, restricted data volumes for most, and a lack of regular surveys that allow analysis of the evolution of these habitats across time, are still the main issues in the investigations on VMEs. New technologies, such as Autonomous Underwater Vehicles (AUVs), would greatly contribute to supporting more widespread data collection, especially in data-poor regions; the overlapping of VME data gathered from AUVs, with fisheries data would be desirable to obtain better maps on VME occurrence and anthropogenic pressures, needed for marine management purposes.

The issue of the 'VME definition' is still prevalent for VMEs researchers and managers. There are various approaches to identifying the presence of VMEs from species/indicator data – whether that be through VME indexes, KDE or modelling thresholds. Data-driven thresholds to define VME and support establishment of move-on rules have been highlighted as a new objective tool. Also noted in several contributions was the **need to explore different features to define VMEs in relation to functional traits** such as habitat complexity or genetic variability (connectivity). There are still improvements to be made, with significant implications for how areas of VME are protected and managed across different seas and oceans. **Learning lessons from different countries** could be a valuable way of exploring new approaches and methods, and dealing with issues such as limited data sets, inconsistencies created from varied data collection methods, and confidence in models.

5. Conclusions

The VME session seemed to reflect the current state of VME research well in several different places across the whole Atlantic, as well as the South Pacific. The need for a more operational definition of a VME, together with improvements in amounts of data collected and identification of thresholds for defining VMEs and move-on rules to prevent SAIs, to inform managers, were some of the most important aspects highlighted in the session. A move towards the use of functional traits to define these thresholds, as well as the need to consider the connectivity between VME features, were also important elements of the discussion.

The VME session was an important contribution to supporting understanding of the 'ecosystem approach' at the ICES ASC. The importance of these deep-sea habitats for the surrounding fauna, including many invertebrate and fish species of commercial interest, has been highlighted.

For future ICES ASCs, we consider it very relevant to include this type of session and, if possible, suggest aligning the topic more with other sessions on fisheries and/or fish biology and modelling. This would help to integrate these topics, which in practice belong together, and provide more opportunities for fish biologists and benthic ecologists to interact and integrate thoughts on problems and solutions for marine ecosystem protection and management.