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Technical measures and environmental risk assessments for deep-sea sponge conservation

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by

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Contents

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Abbreviations and acronyms

CBD	Convention on Biological Diversity
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CEM	conservation and enforcement measures
CMM	conservation and management measures
CP	contracting party
DFO	Department of Fisheries and Oceans (Canada)
DSF	deep-sea fisheries
EAF	ecosystem approach to fisheries
ERAF	ecological risk assessment framework
ESA	ecosystem science assessment
FAO DSF Guidelines	FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas (adopted in 2008)
FAO	Food and Agriculture Organization of the United Nations
GFCM	General Fisheries Commission for the Mediterranean
HSM	habitat suitability model
ICES	International Council for the Exploration of the Sea
MPA	marine protected area
NAFO	Northwest Atlantic Fisheries Organization
NEAFC	North East Atlantic Fisheries Commission
NPFC	North Pacific Fisheries Commission
PECMAS	Permanent Committee on Management and Science
PoE	pathways of effects models
PSA	productivity susceptibility assessments
RFB	regional fishery body
RFMO	regional fisheries management organization
SAIs	significant adverse impacts
SDG	Sustainable Development Goal
SDM	species distribution model
SEAFO	South East Atlantic Fisheries Organisation
SICA	qualitative risk analysis
SponGES	deep-sea sponge grounds ecosystems of the North Atlantic, an integrated approach towards their preservation and sustainable exploitation project
SPRFMO	South Pacific Regional Fisheries Management Organisation
TAC	total allowable catch
UNCED	United Nations Conference on Environment and Development, Earth Summit
UNCLOS	United Nations Convention on the Law of the Sea of 10 December 1982
UNFSA	United Nations Fish Stocks Agreement
UNGA	United Nations General Assembly
VME	vulnerable marine ecosystem
WG	working group

Executive summary

Reducing the impacts of deep-sea bottom fishing in the high seas on non-target and associated and dependent species, including vulnerable marine ecosystems (VMEs) is an important element of an ecosystem-based approach to fisheries management. This approach is an evolution of fisheries management, which incorporates biodiversity protection and is underpinned by legal frameworks including the United Nations Convention on the Law of the Sea (UNCLOS), United Nations Fish Stocks Agreement (UNFSA)[1], the Compliance Agreement[2], and the Convention on Biological Diversity (CBD). Soft law mechanisms including the Code of Conduct for Responsible Fisheries, the United Nations General Assembly (UNGA) Sustainable Fisheries Resolutions, and the International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO DSF Guidelines; FAO, 2009) provide further guidance to reduce impacts from fishing activities. Most recently, the Aichi Biodiversity Targets under the Convention on Biological Diversity (CBD), and the targets through the Sustainable Development Goal framework, specifically SDG 14 strengthen the framework within which States can take actions to reduce biodiversity loss in marine ecosystems. Deep-sea sponges are important contributors to some VMEs and may be considered VMEs on an individual species basis, either through forming dense single and multi-species patches on the seafloor or as part of diverse deep-sea coral/sponge communities. Deep-sea sponges tend to be long lived and slow growing, and perform a variety of ecosystem functions including habitat provision for associated species in both hard and soft substrates, benthic-pelagic coupling, carbon, nitrogen and silica uptake and cycling, particle deposition, water filtration and removal of bacteria as well as current baffling, and alteration of the surrounding microenvironment. While comparatively less well studied than species in shallow water and on coral reefs, deep-sea sponges play similar roles in the ecosystem. However, much less is known about their growth rates, reproduction and recovery than in shallow water systems.

In response to commitments by States to implement the “calls” included within the UNGA Sustainable Fisheries Resolutions and adhere to guidance provided by the FAO DSF Guidelines, RFMOs have implemented a variety of measures to avoid and mitigate impacts of deep-sea bottom fishing on sponges, including identification of sponges as a potential VME indicator, development of encounter thresholds for sponges that trigger move-on rules for fishing vessels, inclusion of sponges in assessments of significant adverse impacts (SAI) of fishing on seafloor ecosystems, area closures and development of exploratory fishing protocols. In some cases, ecological modelling has been used to predict locations of high concentrations of deep-sea sponges, however the majority of information on locations of sponges has been gathered from bycatch assessment of fishing activities and identification in research trawl surveys, with some information derived from in situ sampling with still cameras and video. The comprehensiveness of management measures varies by RFMO and advice on deep-sea sponges may differ depending on the type of ecosystems, type of fishing and fishing gear used, the level of scientific knowledge and taxonomic expertise, as well as the type of fishing that is occurring.

Methods for ecological risk assessment have been established by some States and RFMOs and the FAO DSF Guidelines provide specific elements to be considered in assessing SAI on VMEs. In a fisheries context, the EAF framework as promoted by FAO also includes a risk assessment procedure as one of the key steps in fisheries management planning (FAO 2003, 2005, 2012). In addition, there are multiple risk assessment frameworks that could be applied to the mitigation and avoidance of deep-sea bottom fishing impacts on sponge ecosystems.

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[1] Formally known as the “United Nations 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 and Highly Migratory Fish Stocks,” 34 ILM 1542 (1995)(UN, 2020)

[2] Formally known as the “Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas” (FAO, 1995)

Specific information to inform these risk assessments has been generated by the SponGES project, funded by the European Union Horizons 2020 Blue Growth initiative between 2015 and 2019. SponGES spurred unprecedented research on deep sea sponges in the North Atlantic, resulting in improved knowledge and understanding of sponge distribution, ecological function, impacts of human activities and climate change, role in the deep sea ecosystem and their potential economic contributions through biotechnological components. The scientific information generated allows integration into policy and governance frameworks for deep sea ecosystems.

1. Introduction

The importance of protecting the high seas marine environment from impacts of fishing activities is specifically included in Article 119 of the United Nations Convention on the Law of the Sea (UNCLOS, 1982) both in terms of the stock fished (Para. 1a), and the associated and dependent species (Para. 1b). Implementation of this provision was highlighted in the 1992 Earth Summit (UNCED) and particularly chapter 15 of Agenda 21 on the "Conservation of Biological Diversity", resulting in the 1992 Convention on Biodiversity (CBD). Further focus on marine protection was included in the CBD's Aichi biodiversity targets (CBD, 2020) agreed in 2010 and the Sustainable Development Goals (SDG, 2020) resulting from the 2012 Rio + 20 discussions.

The concern for sustainable use of the marine living resource and the need for the better conservation and management of fishing on highly migratory and straddling fish stocks highlighted at UNCED in 1992 led to the negotiation and eventual adoption of the UN Fish Stocks Agreement which emphasised the important roles regional fisheries bodies (RFBs), in particular the regional fisheries management organizations (RFMOs). Since 2006, triggered by the United Nations General Assembly (UNGA Resolution 61/105), RFBs have addressed concerns relating to possible negative impacts from bottom fishing gears on benthic habitats in the high seas under their measures to protect vulnerable marine ecosystems (VMEs).

More specifically, RFMOs, which have competence to manage deep-sea fisheries in the high seas, have adopted a range of measures (FAO VME DataBase [FAO, 2020]) to prevent destructive fishing practices and contribute towards the protection of marine biodiversity on the sea floor. Broadly, these can be classified as follows:

1. Identification of existing bottom fishing areas ("footprint") where bottom fishing is currently permitted subject to various control measures to protect target and bycatch species;
2. Establishment of "move-on" protocols to be implemented when thresholds of VME catches are exceeded;
3. Areas outside of the footprint where bottom fishing is currently closed but new bottom fisheries are permitted subject to exploratory fishing protocols; and
4. Areas, inside or outside of the footprint, closed to bottom fishing to protect VMEs from Significant Adverse Impacts (SAIs).

The RFMOs agree on and adopt the above spatial measures adapting them to the specific regional context and their implementation is binding for members. In addition, in those areas where an RFMO is lacking, States with fishing vessels, which are known as flag States and that are signatories to UNCLOS, are responsible for conservation in the high seas.

2. Vulnerable marine ecosystems

The VMEs comprise species, communities or habitats that are vulnerable to impacts from fishing activities. The vulnerability of an ecosystem is related to the vulnerability of its constituent populations, communities or habitats.

The call for the development of management measures for the protection of VMEs against Significant Adverse Impacts (SAI) from fishing activities, subsequent to the adoption of a series of UNGA Resolutions in the early-mid 2000 (UNGA Resolutions 58/14 [2004], 59/25 [2005], and 61/105 [2006]) also triggered a process to develop international guidelines for deep-sea fisheries. Subsequently, the FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO DSF Guidelines, FAO, 2009), developed for fisheries whose catch contained species that can only sustain low exploitation rates and where the gear is likely to contact the seafloor, were adopted in 2008. These guidelines provide guidance on criteria for VME identification, on what may constitute a VME, and assessment of impacts from fishing activities, amongst others.

The FAO DSF Guidelines note that VMEs contain populations, communities and habitats that can experience substantial alteration from short-term or chronic disturbance and where recovery from fishery-related impacts may take 5 to 20 years (Paras. 14-20). The following list provides characteristics to be used as criteria for the identification of VMEs: Uniqueness or rarity, Functional significance of the habitat, Fragility, Life-history traits of component species that make recovery difficult, and Structural complexity (Para. 42). The FAO DSF Guidelines provide examples of species groups, communities, habitats and features which often display characteristics consistent with possible VMEs. These include cold-water corals and hydroids, some types of sponge dominated communities, dense emergent fauna, and seep and vent communities, and are typically associated with specific underwater features such as slopes, seamounts, canyons, trenches, vents and seeps. In general, RFMOs regard VMEs as functional benthic ecosystems that are or could be altered substantially by SAI from bottom fisheries. The UNGA Resolutions and FAO DSF Guidelines are adopted, but non-legally binding instruments that serve to assist and guide the RFMOs. VME-related regulations are made by the Commission (the RFMO decision and management making body) with the agreement of members according to the mandate established in their governing conventions based on scientific advice (from the scientific advisory body, internal or external to the RFMO). The scientific body, usually based on a request for advice from the Commission, will look at the evidence that a VME occurs or is likely to occur in some specified area and advise accordingly. The Commission examines the scientific advice and, as appropriate, adopts a measure protecting the VME along with a management boundary. These measures then become binding to contracting and non-contracting cooperating members within the fisheries management structure (i.e. Conservation and Enforcement Measures of the Northwest Atlantic Fisheries Organization, NAFO). VMEs, like fish stocks, have characteristics particular to local and regional environments, and criteria should be adapted accordingly (Para 43 of the FAO DSF Guidelines), as evidenced by the different actions taken by the RFMOs (FAO VME database).

3. Ecosystem function of deep-sea sponges

Marine sponges were not included in the few examples of potential VME organisms provided in UNGA Res. 61/105 (Art. 80 & 83c) and subsequent resolutions, and this slowed their inclusion into the VME fisheries management measures adopted by RFMOs. They were, however, included in the FAO DSF Guidelines (FAO, 2009) and this created the policy mechanism that incentivised data compilation and collection on deep-sea sponges, the development of protection measures as part of the RFMO obligations to protect VMEs that could be impacted by fishing activities. It also triggered support for an increase in research on the ecology and ecosystem functions of deep-sea sponges, which until recently, has been focused on shallow water ecosystems and largely in tropical coral reef environments.

Explorations of deeper water systems included the 1992-1995 Benthic Invertebrates of Iceland waters (BIOICE) focus on "ostur" (*Geodia*), as identified first by fishermen in waters off the Faroe Islands and Iceland (Bruntse and Tendal, 2001). Additional explorations of the *Pheronema carpenteri* (Hexactinellidae) grounds in the Northeast Atlantic (Rice, Thurston and New, 1990) and Geodids in the North Atlantic (Klitgaard and Tendal, 2004; Murillo et al., 2012; Beazley et al., 2013) identified large patches of deepwater sponges as both providers and influencers of habitat for other marine species. These grounds were mainly comprised of Astrophorin (Demospongiae) and Hexactinellid species. Astrophorin sponge grounds tend to be multispecies (Klitgaard and Tendal, 2004; Beazley et al., 2015) while Hexactinellid grounds tend towards single species patches of *Pheronema carpenteri* (Rice et al., 1990) and *Vazella pourtalesi* (Beazley et al., 2018). In 2016, SponGES, a research and innovation project funded under the H2020 Blue Growth BG1 call, was developed with the objective of improving the preservation and sustainable exploitation of deep-sea sponge grounds ecosystems of the North Atlantic. Over four years of research and interaction with stakeholders, SponGES has a) investigated the distribution, diversity, biogeography, function and dynamics of these ecosystems, b) improved innovation and industrial application by unlocking their biotechnological potential, c) enhanced the capacity to model, understand and predict threats and impacts and future anthropogenic and climate-driven changes to these sponge grounds, and d) advanced the science-policy interface for improved resource management and good governance of these ecosystems from regional to international levels across the North Atlantic. Over just a few decades, deep-sea sponge communities have gone from largely unknown ecosystems to being considered foundational biological structures in the benthic environment.

3.1 The ecosystem role of sponges

Results of research studies show that structure forming species in the deep sea perform a variety of ecosystem functions, with distribution on depth, current flow and substrate (Buhl-Mortensen *et al.*, 2010). A review of studies on deep-sea ecosystems confirms the diverse role sponges play in ecosystem functioning (Maldonaldo *et al.*, 2016). This includes higher abundances and diversity of associated species, increased production, organic carbon processing, benthic-pelagic coupling, biofiltration, structural and biological complexity, bioprospecting and climate change mitigation (Table 1).

Table 1. Ecosystem functions of deep-sea sponges.

Ecosystem Function	Source
Bio-engineering habitat, local bottom current changes	Witte *et al.*, 1997; Klitgaard, 1995; Beazley *et al.*, 2015; Murillo *et al.*, 2012; Kutti *et al.*, 2014; Maldonaldo *et al.*, 2016 and references therein
Carbon sequestration, nitrogen and silica cycling	Witte and Graf, 1996; Kutti, Bannister and Fosså, 2013; Cathalot *et al.*, 2015; Maldonaldo *et al.*, 2016 and references therein; Hendry *et al.*, 2019; Pham *et al.*, 2019
Particle deposition	Witte *et al.*, 1997; Kahn *et al.*, 2015; Maldonaldo *et al.*, 2016 and references therein
Filtration and removal of bacterial abundance	Kahn *et al.*, 2015

The relative importance of these function is dependent on sediment type, size and density of sponge grounds, longevity of species, sponge morphology and structure, location along the depth gradient and total biomass (NAFO WG ESA, 2018)(Table 2).

Table 2. Preliminary compilation of VME biological traits analysis, including modalities, functions and potential vulnerabilities to fishing for coral and sponges (source: NAFO WG ESA, 2018)

Trait	Modalities	Functional links	Impact of Fishing Hypotheses	Reference
Maximum adult size	Very small < 100 mm Small 100-300 mm Medium 301-500 mm Large > 500 mm	Productivity, Biodiversity provision, Filtration capacity, Carbon sequestration	Larger sponges are expected to be more vulnerable to bottom contact fishing gears	Sainsbury, Campbell and Whitelaw, 1992
Morphology	Massive-globose Massive-irregular Tubular/Vase/Cylindrical Flabellate Arborescent/Branching Cushion/Papillate Thin sheet Stalked Filiform (whip)	Productivity, Biodiversity provision, Filtration capacity, Carbon sequestration	We expect morphology and size to interact with catchability. For example, 100% of branched sponges less than 300 mm, and 80% of branched sponges between 301 and 500 mm in height, passed under the net	Wassenberg *et al.*, 2002

Table 2. Continued

Trait	Modalities	Functional links	Impact of Fishing Hypotheses	Reference
Degree of Contagion	Highly aggregated (Habitat forming) Small patches Solitary	Biodiversity provision, bio-engineering habitat (e.g. sediment stability), local bottom current changes	We expect species forming aggregations will be more vulnerable to fishing than solitary species based on probability of encounter	n.a
Feeding mode	Filter feeder Carnivore Suspension feeder	Energy transfer (Trophic position)	We expect filter feeding sponges to be more susceptible to impacts of sedimentation caused by fishing than carnivorous sponges	n.a
Preferred substrate inhabiting	Hard (rock) Gravel/Pebbles Soft (mud/sand) Epizoic (on other fauna)	Bio-engineering habitat (e.g. sediment stability), local bottom current changes	We expect sponges living on soft sediment to be more susceptible to impacts of sedimentation caused by fishing than sponges living on hard bottoms	n.a
Rigidity	Rigid Flexible	Provides stable structure and substrate for others organisms to attach to	More rigid is more sensitive to bottom contact fishing disturbance	n.a
Adult mobility	Sessile Sedentary	Bioturbation	Sessile is more susceptible to the effects of bottom contact fishing disturbance	n.a

While research on deep-sea sponges has increased over the past two decades, there are still knowledge gaps in reproductive methods and timing, growth rates, and recovery rates. Impacts of climate change on sponges are unknown, although experimental research is increasing, including testing sponge respiration rates in the context of temperature increase. While there remains uncertainty in some aspects of sponge ecosystem function, ecological risk assessment should be based on the precautionary approach.

4. Regional measures for protecting sponges

4.1 Inclusion of sponges as VME indicator species by the RFMOs

The RFMOs have identified VME indicator species as an aid to assist in the identification of VMEs, typically when encountered (caught) by commercial fishing vessels. RFMOs, through scientific surveys, began identification of specific ecosystem elements and species that met the VME criteria which largely aligned with those provided by the FAO DSF Guidelines (para 42). In the Northwest Atlantic, focused research through the NEREIDA program as well as Canadian research surveys, resulted in the identification of specific sponge species as VME indicators in the NAFO area (Table 3). The North East Atlantic Fisheries Commission (NEAFC) has identified various deep-sea sponge aggregations as VME indicators while other RFMOs include sponges more generally as VME indicators.

The identification of most VME indicator species and in particular of sponges is very challenging and is facilitated by the use of identification guides that have been produced by RFMOs for most regions e.g. Northwest Atlantic (Kenchington *et al.*, 2015), Southeast Atlantic (Ramos *et al.*, 2009), Mediterranean Sea (FAO, 2017a, b) and Indian Ocean (FAO, 2016). Due to these difficulties, VME indicators may be given at a higher taxonomic level, such as phylum Porifera in the Southeast Atlantic (South East Atlantic Fisheries Organisation, SEAFO), and classes hexactinellida and demospongiae in the Southern Ocean and south Pacific Ocean (Convention on the Conservation of Antarctic Marine Living Resources, CCAMLR, and South Pacific Regional Fisheries Management Organisation, SPRFMO) or down to representative species in the Northwest and Northeast Atlantic (NAFO and NEAFC). Sponges have been included in the Contracting Party regulations for their vessels fishing in the high seas of the Indian Ocean and details are provided by the Southern Indian Ocean Fisheries Agreement (SIOFA) on their website. Sponges are not included among the VME indicators of the North Pacific (North Pacific Fisheries Commission, NPFC), and indicators have yet to be selected for the Mediterranean (General Fisheries Commission for the Mediterranean, GFCM) (Table 3).

Table 3. Sponge VME indicators adopted by RFMOs (other indicator taxa not included in this table).

Source	**VME indicator (Phylum Porifera)** (*species* family)(FAO ASFIS Code)	**Data collection protocol**	**Threshold (for 2019)**	**Encounter response**
NAFO CEM 2019 Annex I.E	*Asconema foliatum,* Rossellidae (ZBA) *Aphrocallistes beatrix,* Aphrocallistidae *Asbestopluma* (*Asbestopluma*) *ruetzleri,* Cladorhizidae *Axinella* sp. Axinellidae *Chondrocladia grandis,* Cladorhizidae (ZHD) *Cladorhiza abyssicola*, Cladorhizidae (ZCH) *Cladorhiza kenchingtonae*, Cladorhizidae (ZCH) *Craniella* sp.,Tetillidae (ZCS) *Dictyaulus romani*, Euplectellidae (ZDY) *Esperiopsis villosa*, Esperiopsidae(ZEW) *Forcepia* spp., Coelosphaeridae (ZFR) *Geodia barretti*, Geodiidae *Geodia macandrewii*, Geodiidae *Geodia parva*, Geodiidae *Geodia phlegraei*, Geodiidae *Haliclona* sp., Chalinidae (ZHL) *Iophon piceum*, Acarinidae (WJP) *Isodictya palmata*, Isodictyidae *Lissodendoryx (Lissodendoryx) complicata*, Coelosphaeridae (ZDD) *Mycale (Mycale) lingua*, Mycalidae *Mycale (Mycale) loveni*, Mycalidae *Phakellia* sp., Axinellidae *Polymastia* spp., Polymiastiidae (ZPY) *Stelletta normani*, Ancorinidae (WSX) (Stelletta) *Stelletta tuberosa*, Ancorinidae (WSX) (Stelletta) *Stryphnus fortis*, Ancorinidae (WPH) *Thenea muricata*, Pachastrellidae (ZTH) (Thenea) *Weberella bursa*, Polymastiidae	Observer to identify to lowest level; vessel master to report encounter above threshold to Secretariat	300 kg sponges	Report encounter. Move 2 nmile. Temp closure outside of footprint. SC review
NEAFC 19/2014 (amended)	3. Deep-sea sponge aggregations a. Other sponge aggregations: Geodiidae, Ancorinidae, Pachastrellidae b. Hard-bottom sponge gardens: Axinellidae, Mycalidae, Polymastiidae, Tetillidae c. Glass sponge communities Rossellidae Pheronematidae	Simply report encounter. Sea bed mapping preferably (with echosounders)	Trawl and non-LL: 400 kg sponges LL: 10 VME Indicators per 1000 hooks (1200 m line)	Report encounter. 2 nmile move on. Temp closure. Review temp closure.
SEAFO CM 30/15	"… and sponges comprising taxa listed as VME indicators by the SEAFO SC." (Annex 6 para 1) PFR Porifera (Phylum) Sponges (SEAFO, 2016, p.36; SEAFO, 2017, p. 16)	Observers record to lowest taxonomic level and collect samples.	Trawl 600 kg live sponges (existing fishing area) 400 kg live sponges (new fishing area) Longline and pots >=10 units (kg or litres) in 1200 m (1000 hooks) of line all areas	1 or 2 nmile move on. Report to ES and CP. Temp closure outside footprint. Area assessed by SC

Table 3. Continued

Source	VME indicator (Phylum Porifera) (*species* family)(FAO ASFIS Code)	Data collection protocol	Threshold (for 2019)	Encounter response
SPRFMO CMM 3-2019	Sponges (Porifera: Demospongiae and Hexactinellidae) Annex 5	Report encounter	Annex 6A One tow for a single VME indicator taxa Sponges 50kg Annex 6B One tow for three or more different VME indicator taxa Sponges 5 kg plus two other groups at 1-5 kg	Move 1 nmile. Temp closure. Review by SC (para 26-33)
SIOFA CMM 2019-01	Annex 1:Porifera (PFR), which can be, if possible, detailed in recording as: Hexactinellida (HXY) (Class), Demospongiae (DMO) (Class) Established interim benthic protected areas	Observers must collect VME data CCPs shall report any such encounter in national reports to Scientific Committee	Longline catch/recovery of 10 or more VME-indicator units Trawl 300 Kg of sponges in any tow.	For long lines, 1nm from midpoint of fishing track, for trawls 2nm either side of trawl track any trawl track
CCAMLR CM 22-07(2013)	VME Taxa Classification Guide Porifera: Hexactinellida (Glass sponges), Demospongiae (Siliceous sponges)	Provide details of VME taxa	>=10 units or >=5 units 'Line segment' means a 1 000-hook section of line or a 1 200 m section of line, whichever is the shorter, and for pot lines a 1 200 m section.	>=10 units – Report and move away (temp 1nm radius closure >=5 - report
NPFC CMM 2018-05/06	Sponges not specifically included as VME Indicators (but corals are) nor by SC			
GFCM	GFCM have closed some VME areas but have no measures for encounters. No indicators selected			

Of the RFMOs who have included sponges within a VME indicator list NAFO is the most comprehensive with 29 sponge indicator species. At the 2019 scientific council meeting of NAFO (NAFO, 2019), FAO ASFIS codes were assigned to 18 species of sponges to facilitate the reporting by observers during fishing activities.

4.2 Use of encounter thresholds for VMEs establishment

To minimize impacts on VMEs, RFMOs have established specific measures aimed at avoiding SAIs on areas where there are significant concentrations of benthic species. In this context, specific threshold values of catches of VME indicator species have been set, above which specific actions needs to be taken to evaluate if the vessel may be fishing within a VME. For sponges, the thresholds are at the phylum level and range from 300 to 600 kg per trawl, and so identification to species level is not required. Lower thresholds are often used for other bottom fishing gears, such as longlines, that retain very little sponge in the catch (Table 3). Catches above threshold elicit different management responses according to the rules of the RFMOs, which may include the reporting of the encounter, move-on requirements and the possibility of temporary closures.

The selection of threshold levels for commercial bottom fishing vessels has been based on "experience" or "expert judgement" rather than any hard scientific analysis, and has tended to be reduced over time. For example, the sponge threshold in NAFO has been 1000 kg (2009), 800 kg (2010-2011), 600 kg and

400 kg (inside and outside of the fished area, 2012), and 300 kg (2013-2018) (NAFO CEM, 2009-2019). Scientific work to try to identify an objective means to set threshold levels have been undertaken in the Northwest Atlantic (Kenchington *et al.*, 2009, 2011; Cogswell *et al.*, 2010). Results from these studies provide a lower threshold value that separates significant concentrations of aggregated sponges from more sparsely distributed scattered sponge populations and can be useful in delineating VME areas. Though it is necessary to have a threshold for eliciting a management response, the use of the threshold to elicit the reporting of encounters with VME indicator species, including sponges, limits information collected where sponges below the encounter threshold are not reported.

NAFO (NAFO, 2009b, p. 33) analysed sponges catches by research vessels deploying bottom trawls in the high seas of the Northwest Atlantic from 1995 to 2008 and plotted those positions where sponges had been present and absent, and where catches exceeded 75 kg (Figure 1). Though there are problems in interpreting zero catches (i.e. where catches were simply not recorded), the plot gives a clear indication as to where sponges are absent, present in lower densities and present in high densities. The high-density areas were interpreted as containing significant concentrations of sponges and should be considered to contain VMEs (NAFO, 2006).

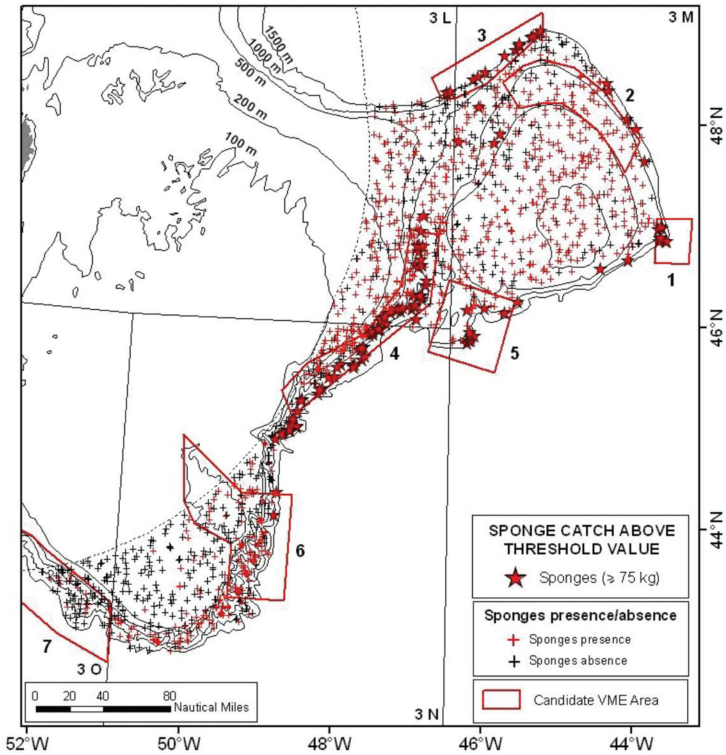

Figure 1. Catches of sponges in research cruises in the NW Atlantic 1995-2008. (source: NAFO, 2009b, p. 33).

More recently, the question of the applicability of threshold levels across all species in a taxa has been discussed. The NAFO sponge threshold is most relevant the massive ball sponges (*Geodia*) but is considered too high for some of the lighter sponges, e.g. the glass sponges. The ecosystem functions of glass sponges on the Flemish cap are currently being investigated (Murillo *et al.*, 2020).

Encounters with sponges above threshold, in addition to reporting, may also trigger a move-on rule and a temporary closure, though details vary according to the region (Table 3). The move-on rule, has been subject to much debate with respect to its usefulness for the protection of long-lived sedentary species of sponges (and corals). The establishment of a temporary closure following encounters above threshold serves to protect the immediate area around the encounter until further investigations can confirm or refute the presence of a VME. Currently, the establishment of a temporary closure following an encounter applies in the Northwest Atlantic outside of the fishing footprint (NAFO), Northeast Atlantic (NEAFC), Southeast Atlantic (SEAFO), Southern Ocean (CCAMLR), and some Contracting Parties in the Southern Indian Ocean (SIOFA) with the closure being generally of 1–2 nautical mile (nm) radius.

4.2.1 Sponge encounters above threshold

CCAMLR, who manages fisheries on the Southern Ocean, is the only regional body to have reported encounters with VME indicators above threshold. These were taken in the longline fishery for Patagonian toothfish and have resulted in the notification of 77 VME Risk areas (CCAMLR, 2018). In terms of VME indicator specimen numbers and weights, catches are recorded above the threshold of 10 VME units per line segment (i.e., per 1 000-hook section of line or a 1 200 m section of line, whichever is the shorter, and a 1 200 m section for pot lines) (Table 4). Catches above threshold averaged 12.2 kg of sponges and 4.8 kg of other VME indicator species, mainly gorgonian corals. The highest catch of sponges recorded was 68 kg in a single line segment. Catches below threshold were not recorded in the VME registry (CCAMLR, 2018), but would have been provided to CCAMLR through their scientific observer scheme. In NAFO, no encounters above the threshold have been reported from commercial fishing activity; however research surveys by Contracting Parties have reported "significant catches" that were well above 75 kg within the known VME polygons identified by the NAFO Scientific Council that continue to be open to bottom fishing (NAFO, 2018). SIOFA, through specific Contracting Party regulations, is the most recent RFMO to adopt interim bottom fishing measures, including a VME threshold for sponges of 300 kg (SIOFA, 2019a).

Table 4. Combined catches by commercial toothfish fisheries in CCAMLR of VME indicator taxa above threshold that resulted in the designation of 77 risk areas (source: CCAMLR, 2018).

VME indicators	Percent	Av. kg per risk areas
Sponges	46.8	7.96974
Siliceous sponges	24.4	4.165586
Glass sponges	0.4	0.069481
Gorgonians	14.9	2.536091
Hydrocorals	7.6	1.299091
Sea anemones	3.4	0.584416
Other VME indicators	2.5	0.4
Total	100.0	17.0

4.2.2 Sponge encounters below threshold

Management measures for commercial bottom fishing vessels require the formal reporting of encounters of VME indicator species when the catch is above the agreed threshold value (Table 5). The reporting of catches below the threshold by commercial vessels is mainly limited to RFMOs with scientific observer programs and is a requirement when undertaking exploratory fishing activities outside of the fishing footprint. The majority of sponge species identification and collection below the threshold originates from dedicated stock assessment or ecological research vessel surveys, particularly when there is a goal to assess all catch (e.g. NEREIDA surveys in the Northwest Atlantic and others reported to the ICES VME database (see ICES [2018] and earlier reports). Commercial vessels do, in some cases, report encounters below threshold, such as observer reports in the high seas of the SE Atlantic Ocean (SEAFO, 2020). Additional work in the Northwest Atlantic analysing sponge spicules taken from sediment core samples has shown that sponge grounds were not ubiquitous even in historical times, though an analysis of research vessel catches has shown that there is a wide low-level distribution (Cogswell *et al.*, 2010). This has been modelled with species distribution models that quantitatively assesses the amount of sponge throughout the entire area. Further progress is being made on modelling of specific species as a result of efforts undertaken through the SponGES project, and will help to provide guidance on distribution of specific types of sponges, rather than sponges generally.

4.2.3 Sponge removal by bottom fisheries

NAFO's Scientific Committee (SC) is currently working to improve the mapping of commercial fishing effort by gear to allow for estimates of potential impact on VMEs and VME indicator species (Figure 2; NAFO, 2018, p. 53), and it is evident that fishing effort is concentrated on a few specific locations with light effort throughout most of the area. More detailed analyses show, in some cases, that fishing effort can be close to closures and can impact on sub-threshold marginal VME grounds (Figure 3; NAFO, 2014, p. 77).

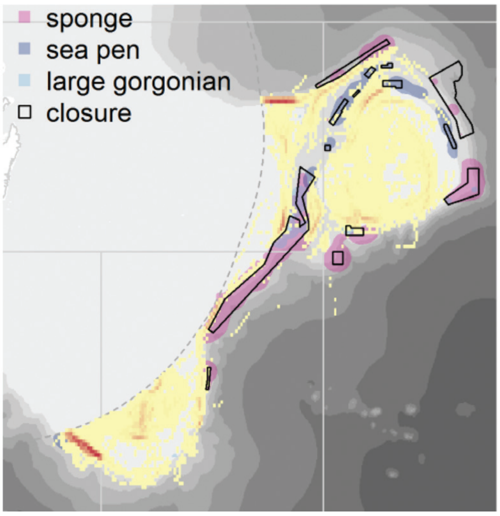

Figure 2. Cumulative fishing effort maps (hrs fished/cell) from 2016 VMS data filtered for speeds within 1-5 knots (source: NAFO, 2018, p. 53).

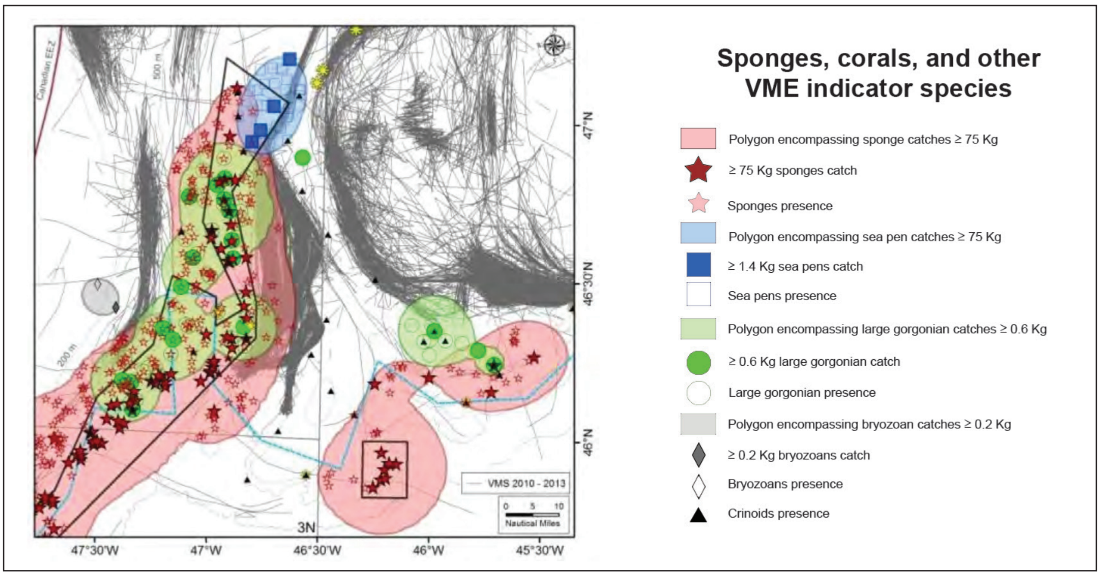

Figure 3. NAFO VME Area 2 northern portion and Area 3 Beothuk Knoll. VMEs and VME indicator species (top) from kernel analysis and fishing positions (mainly bottom trawl) during 2010-2013 using VMS data (source: NAFO, 2014, p. 77).

If the commercial fishing effort is partitioned among VME closures, outside VME closures but within the VME polygons, and outside the polygons but within th fishing footprint, it is seen that the greatest removals occur in the marginal VME areas followed by the large overall fished areas (Table 5).

Table 5. Sponge catches by research vessels using bottom trawls in the NW Atlantic during 2002 (adapted from NAFO, 2017, p. 23).

Region	Number of hauls	Total catch (kg)	Number hauls with >75 kg	Average catch per haul (kg)	Relative fishing effort	Potential removal per year (kg)
Outside VMEs and closures	3769	4320	4	1	1000	1000
Inside VME and outside closure	322	3772	13	12	100	1200
In VME closure	293	126714	116	432	0	0

If it is assumed that important ecosystem sponge functions, for example, carbon sequestration or filtration, are a simple function of sponge weight rather than density, then it is feasible that the impacts on widely distributed low density grounds could be cumulatively significant in terms of impacts on ecosystem services. Whereas the above scenario is based on mathematical models, there is sufficient information to provide preliminary assessments of effectiveness of the closures and risk of SAIs. This is currently within the work plan of NAFO's who are working towards developing methods to understand the services provided by benthic ecosystems including sponges and the effects and consequences of significant adverse impacts and lower level impacts (NAFO, 2018, p. 52). Whereas the above may or may not result in changes to existing management regulations, it does highlight the need to better understand impacts through environmental risk assessments. Such risk assessments will depend on improvements in data collection from fishing activity and NAFO has made recent progress in sponge species identification, in the requirement of reporting of haul by haul data from fishing activity as well as the addition of FAO observer codes to specific sponge species (NAFO CEM, 2005-2019). NAFO updated its sponge identification guide in 2015 (Kenchington *et al*., 2015). To date, no additional measures have been agreed based on new indicator species and NAFO VME's are currently being reviewed by the Scientific Council with results on areas vulnerable to SAI's expected in 2021.

4.3 Areas currently closed to protect sponge VMEs

A review of RFMO measures and supporting information on VME areas closed to bottom fishing provides a list of those that include sponges as a taxa requiring protection (Table 6). However, many of the VME closures are precautionary and lack any detailed benthic survey information. Further, most are designed to protect benthic ecosystems and sponges may be found in close association with other VME indicator species, including corals. In some cases, concentrations of sponges have been identified, such as the concentrations of Geodid sponges in the Northwest Atlantic and *Pheronema carpenteri* patches in Hatton and Rockall Bank in the Northeast Atlantic. While in other areas, sponges are protected as part of a broader VME area and as a suite of VME indicator species/groups. As data collection improves across RFMOs, this information should be incorporated into impact assessments and subsequent precautionary management measures.

Table 6. VMEs adopted by regional fisheries bodies that include sponge occurrence as one of the reasons for their closure.

1. NW Atlantic (NAFO): 21 VMEs in total		
Area	**VME Inside closure**	**Notes**
Area 1 Tail of Grand Bank	Sponges	
Area 2 Flemish Pass/Eastern Canyon	Sponges & large gorgonians	Sponges occur outside of current closure
Area 3 Beothuk Knoll	Sponges	Sponges occur outside of current closure
Area 4 Eastern Flemish Cap	Sponges & large gorgonians	Sponges & large gorgonians occur outside of current closure
Area 5 Northeast Flemish Cap	Sponges	
Area 6 Sackville Spur	Important sponge grounds	The sponge ground VME extends beyond the current closure. No significant concentrations have been found outside the closed area.
Areas 8 – 10 and 12	Sponges and sea pens	
2. NE Atlantic (NEAFC): 15 VMEs in total		
Area	**VME taxa in description**	
Northern MAR	Sponges and corals	
Altair	Sponges mentioned	

Table 6. Continued

Antialtair	Sponges mentioned	
Edora Bank	Sponges and corals	
Hatton Bank 2 Area 1	Sponges and gorgonians	
Hatton-Rockall Basin Area 2	Sponges (*Pheronema carpenteri* and *Hyalonema* stalked sponges) at approximately 1150 m water depth	
Rockall Bank	Sponges and corals	
Southwest Rockall Area 2	Sponges and *Lophelia* reefs	
3. SE Atlantic (SEAFO): No VME indicators mentioned in their 12 VME Closures (mainly precautionary)		
4. Mediterranean (GFCM): 1 of 5 closures mentioned sponges		
Area	**VME Inside closure**	**Notes**
Eratosthenes Seamount	A rare deep water sponge, *Hamacantha implicans*	
5. Southern Ocean (CCAMLR): 59 of 76 risk areas were identified by catches of VME indicator units above the threshold for risk areas of 10 units in a single line segment, which included sponges among other indicators. The list of sponge indictors in VMEs was not recorded on the CCAMLR website.		
6. North Pacific (NPFC): Koko and C-H seamounts closed to protect possible VMEs but sponges are not mentioned.		
7. Indian Ocean (SIOFA), South Pacific (SPRFMO) and SW Atlantic: No internationally agreed VMEs.		

4.4 Establishment of existing bottom fishing area and exploratory fishing protocol

GFCM was the first in 2005 to formally adopt spatial management measures to effectively manage fisheries and limit their ecological impacts by prohibiting the use of towed dredges and trawl nets fisheries at depths beyond 1000 m, which was outside of the areas where fishing occurred (GFCM Recommendation GFCM/2005/1).

Many of the other deep-sea RFMOs have defined an "existing bottom fishing area" based on the presence of bottom fishing at some specified level within a recent defined time frame. They then adopted measures that would apply inside and outside of this area. This was done to freeze the permitted bottom fishing areas to recent levels in terms of area and to a lesser extent effort. It recognises that the fisheries and ecosystems are relatively well known and well studied within "the existing bottom fishing area" and often poorly known outside of this. Some RFMOs, e.g. NAFO, use the term "footprint" as being equivalent to the bottom fishing area, however, the current existing bottom fishing areas do not necessarily include those areas fished during the early intensive exploratory phases during the 1960s and onwards. The current "footprint" may therefore not reflect the full extent of bottom fishing activities, which are of relevance to long lived species that may form VMEs. Future references to "footprint" here refer to the recent area fished with bottom contact gear in the reference period.

RFMOs have also developed and adopted exploratory fishing protocols to allow for controlled and sustainable expansion for new bottom fisheries outside of the fishing footprint or inside the fishing footprint when the effort or fishing method changes significantly (NAFO CEM 2018 Art. 15.2 and NEAFC Rec. 19/2014 rev. Art 2.d). The protocol includes a strict fishing plan that monitors catches of target and bycatch species over an initial period of usually 2-3 years. The results are examined by the region's Scientific Council and Commission and approved if catches of target species are sustainable and if no SAIs occur to bycatch species including VMEs.

The NPFC has also recently adopted an exploratory fishing protocol (NPFC CMM, 2019-05). To date, CCAMLR, SEAFO and SPRFMO have assessed applications for exploratory fisheries (CMM 4.14 and

4.14b). Many of the CCAMLR high seas fisheries are regarded as exploratory and application are made each year to continue these. SAIs to VMEs are mitigated through the CCAMLR bottom fishing measures based on encounter protocols. SEAFO have had several applications for exploratory Patagonian toothfish fisheries in several areas outside of the existing fishing footprint using trotlines (SEAFO, 2016, p. 4, 18-21; 2017, p. 10-11; 2018, p. 10). In general, SEAFO uses the VME indicator threshold as a measure of there being a potential VME in the area of exploratory fishing and has developed guidelines for the assessment of exploratory fisheries (CMM 30-2015, Annex 3). In a recent assessment, SEAFO SC noted concerns that the mapping of VMEs was not undertaken by the applying CP prior to exploratory fishing and that the assessment by the Scientific Committee of both the identification of VMEs and associated impacts on VMEs is difficult based on the catches of VME indicator species by the trotline fishing gear when retention is so low (SEAFO, 2017, p. 10-11).

SPRFMO have recently had an exploratory fisheries applications for bottom longlining for toothfish in 2017-2018 from New Zealand (CMM 4.14)(SPRFMO, 2016) and from the EU (SPRFMO, 2018a, p. 42-44) and pot fishing for crabs in 2019-2020 (CMM 4.14b)(SPRFMO, 2018b). No detailed analyses on VME and sponge bycatch has been presented yet.

NEAFC had three applications for exploratory fisheries in 2015, though none received approval though none were believed to threat VMEs habitat. NEAFC does have "Procedures and standards for the Permanent Committee on Management and Science (PECMAS) consideration of proposals for exploratory fishing pursuant to Rec. 19: 2014 (NEAFC, 2015). These provide detailed guidance for an assessment of an exploratory fishery with respect to vulnerable marine ecosystems to be undertaken by PECMAS and optionally with advice from ICES. The objective is to evaluate the risks of significant adverse impact on VMEs that may be encountered during the fishery in accordance with the precautionary approach and to account for cumulative effects. Consideration is to be given to experiences in similar regions and fisheries, and on mitigation measures to avoid SAI to VMEs. Approval is more likely if the risk of SAI to VMEs is seen to be zero or low. No absolute limit reference points or thresholds are given and there is no mention of using NEAFC's encounter threshold limits. Encounters during exploratory fishing with VME indicators above threshold are subject to the same regulations as encounters during normal operations within the existing bottom fishing areas, i.e., reporting, move-on rule and temporary closure.

5. Risk mitigating actions for sponges in the RFMOs

5.1 Reducing spatial overlap

The current approach to reducing the risk of SAIs to VMEs from bottom fisheries is to map the fisheries and VMEs and to close fisheries that spatially overlap with the VME areas. VMEs, as per the criteria on the FAO DSF Guidelines, are rare, spatially distinct, and typically occurring on a physical feature. In the beginning of the VME process, it was normal to think of VMEs as the area delineated and closed by the regional management body to prevent SAIs. This was normally confined to the core area where significant concentrations occur to form ecosystems; densities decline away from these core areas. In general, the measures protect the core areas and it is recognised that lower densities of sponges exist outside but near to these areas.

In the Northwest Atlantic, the NAFO Scientific Council has mapped areas of high concentration of specific taxa based on survey results and modelling to estimate boundaries with the closed area overlain (see Figure 3 for example). In 2015, NAFO assessed the areas of known VMEs at risk of SAIs, and found that 64% of the area of the known sponge grounds were outside the closed area, with 45% of the sponge biomass being at risk of SAIs (NAFO, 2015). However, and following the FAO DSF Guidelines, NAFO had protected the high density areas where significant concentrations occur. Further work is needed to examine the consequences of SAI on these areas outside of the closures, but encounter protocols do apply in these areas and are designed to identify new areas where SAI may occur. As of 2018, no further adjustments have been made to the sponge VMEs closure boundaries. In 2016, NAFO analysed catches of sponges by research vessels, with recorded catches outside of the VMEs closures as > 2000 kg, thus indicating that some VMEs outside of the closed areas were at risk from bottom fishing impacts (NAFO, 2016b). NAFO has been improving techniques to map bottom fisheries by gear type using VMS and logbook information to better understand spatial and cumulative risks to VMEs though results are not yet available (NAFO, 2018, p. 52, 90). NAFO will review its VME closures in 2020 and complete updated impact assessments in 2021, using the full criteria outlined by the FAO guidelines. Preliminary information on VME traits has been developed, with a view towards better assessing VME ecosystem function and relative vulnerability to impact (Table 2, as reported in NAFO WG ESA, 2018 p. 53 as Table 2.5).

Maps of catches of VME indicator species provided by ICES are also available for the Northeast Atlantic. A map of the distribution of sponges on the Rockall/Hatton Bank obtained from a variety of sources, with the NEAFC VME closures overlain, shows catches outside of the closures (Figure 4).

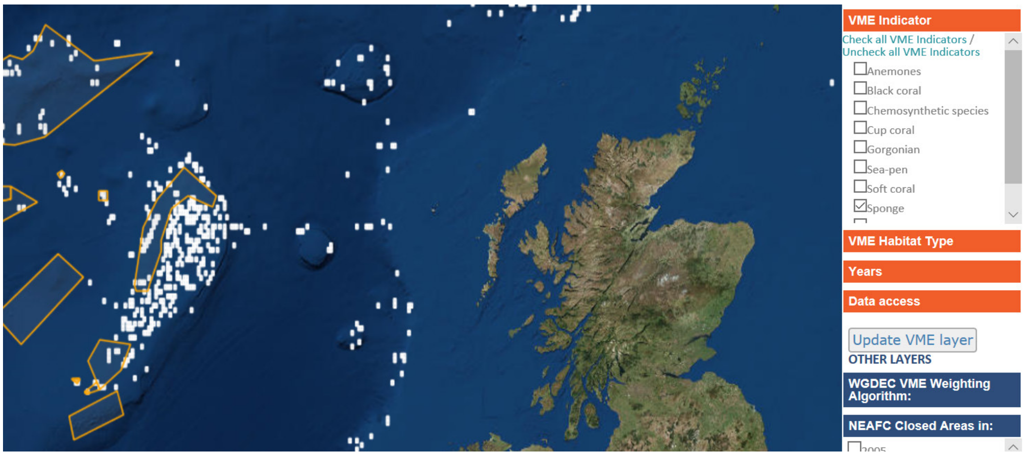

Figure 4. ICES VME data mapping facility with sponge records and NEAFC VME closures effective 2015 (source: http://vme.ices.dk/map.aspx)

However, the sponge concentrations southwest of the Rockall Bank closure are low, which indicates that the chance of encountering a VME here is small (Figure 5). ICES in a re-assessment of the NEAFC VME closures in 2017 concluded that the VME closures are appropriate though subject to change when new information is received (ICES, 2017, p. 89-90).

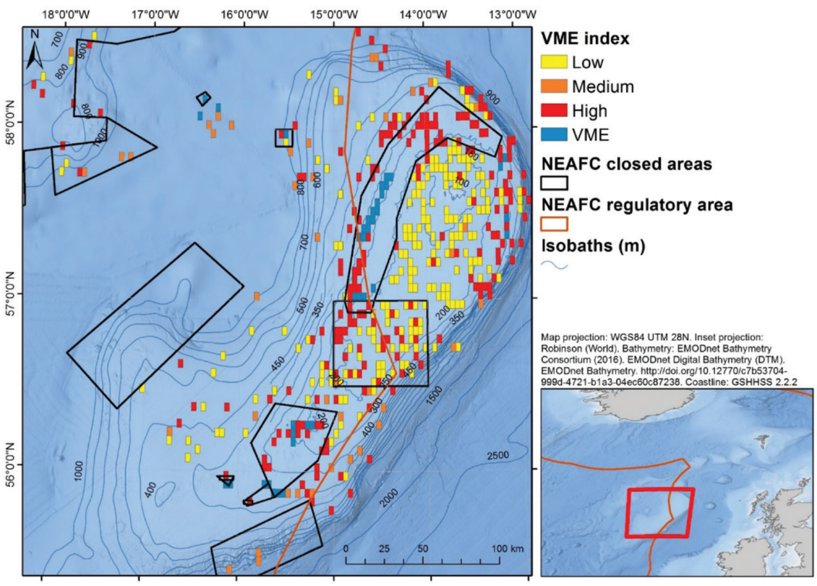

Figure 5. Output of the VME weighted algorithm for the Rockall Bank area, showing the VME Index; the likelihood of encountering a VME within each grid cell (ranging from low to high). Note this included all (not only 2017) records from the ICES VME database. (source: ICES, 2017, Figure 3.2, p. 11).

5.2 Improving the fishing footprint

NAFO's "existing bottom fishing areas" (footprint) was derived from VMS data and/or other available geo-referenced data indicating that bottom fishing activities have been conducted at least in two years within a reference period of 1987 to 2007 (NAFO CEM 2010, Art 1bis.3). There has always been the possibility to revise the map based on new information (NAFO CEMs, 2010-2018). The adopted map was a simple polygon with all gears and levels of effort combined (Figure 6).

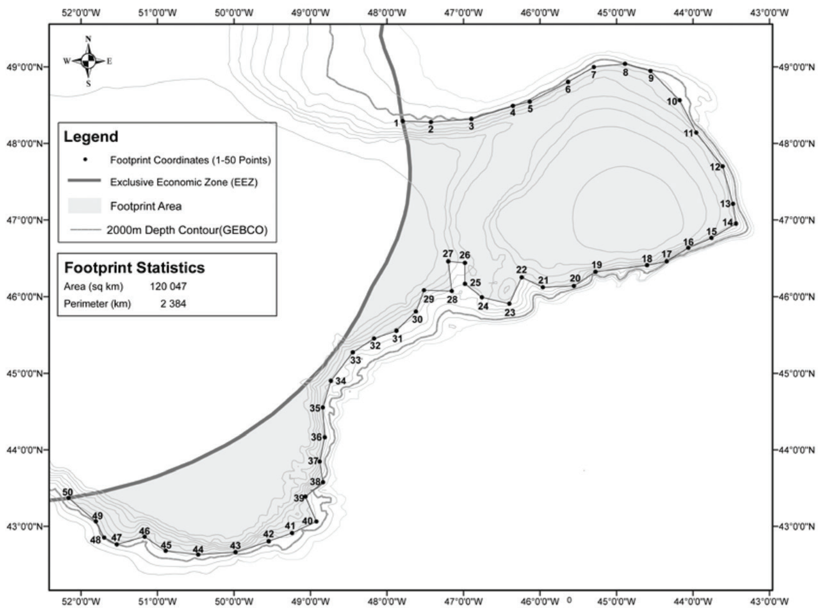

Figure 6. NAFO existing bottom fishing area (fishing footprint)(source: NAFO CEMs 2018, https://www.nafo.int/Fisheries/Conservation).

Even with the information in the original analysis (NAFO, 2009a), and especially in the updated spatial analysis of fishing effort (Figure 2), it can be seen that effort is very unevenly distributed. The usefulness of the fishing footprint would be improved by including gear and effort information. Further, without improved data collection on fishing effort within the footprint, it is difficult to monitor changes in fishing patterns and apply the underlined part of the exploratory fishing protocol that states "Definition 2. "Exploratory bottom fishing activities" means bottom fishing activities conducted outside the footprint, or within the footprint with significant changes to the conduct or in the technology used in the fishery" (NAFO CEM 2018, underline added). Bearing in mind that this footprint or "existing bottom fishing area" was set for the reference period 1987–2007. With the advent and use of vessel monitoring systems, such analyses are now routinely undertaken and updated. Further, and with the advent of climate change, improved monitoring and modelling of fishing patterns will assist predictions of future stock change and improve management and mitigation measures for sponge grounds (Figure 7).

NEAFC's existing fishing footprint was "based on information concerning bottom fishing activities in the period 1987-2007 (NEAFC Rec. 19-2014, Rev. Article 4). In NEAFC, "Exploratory bottom fishing" means all commercial bottom fishing activities outside existing bottom fisheries and areas closed to bottom fishing for VME protection, or if there are significant changes to the conduct and technology of bottom fishing activities within existing bottom fishing areas (NEAFC Rec. 19-14 Rev, Article 2.d, underline added). As for NAFO, it is a combined footprint for all gears over a wide range of effort.

Subject to confidentiality agreements, by both NAFO (NAFO CEM, 2018 Art. 29) and NEAFC (e.g. NEAFC Rec.14-2017), there has been increasing availability of information on fishing vessel positions and gear deployment for scientific purposes and this has improved monitoring of targeted stocks, bycatch and protection of VMEs.

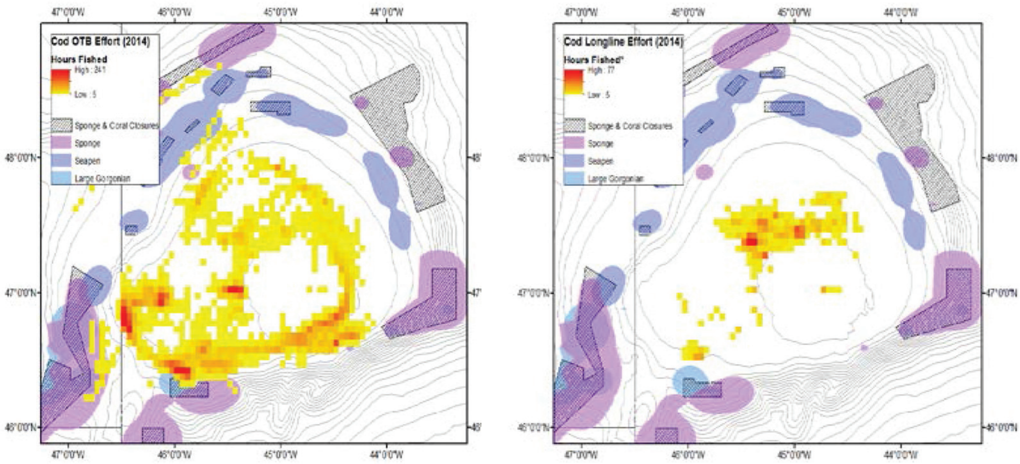

Figure 7. Spatial modelling of fishing patterns by gear and year that could be used to look at potential impacts caused by significant changes in fishing patterns overlayed with SDM of sponges. (source: NAFO, 2016a, p. 257-258).

5.3 Gear information, modifications and restrictions

Currently 3-4 main gear types are used for bottom fishing: bottom trawls, gillnets, longlines, and pots, and each can be rigged or deployed differently to minimise interactions with the seafloor. Further, mid-water gears can touch the seafloor either accidentally or by design. The following are examples where modifications have been undertaken to reduce impacts to benthos, including sponges:

Bottom trawls: NAFO Scientific Council have been requested by their Commission to evaluate impacts from bottom fisheries and require better information on gear configurations, such as door spread (NAFO, 2018, p. 52). Part of this study will highlight how gear configurations affect impacts and how gear modifications can reduce impacts. The use of bottom trawls is typically allowed within the existing bottom fishing areas of the RFMO Convention Areas. An exception to this is in the high seas of the Southern Ocean where their use by commercial vessels is restricted only to specified areas, which currently is sent to only to division 58.5.2 (CCAMLR CM 22-05, 41-08, 42-02).

Mid-water trawls: NAFO have had concerns regarding the use of mid-water trawls fishing for redfish and their design that can allow contact with the seafloor during normal use (NAFO, 2018, p. 30). NAFO amended their conservation measures such that no portion of mid-water trawls is designed to be or is operated in contact with the bottom at any time (NAFO CEM 2018, Art 13.2f, 8). This restriction was extended to seamount fisheries and had implications for the pelagic alfonsino fishery in the Corner Rise seamount VME closure. This alfonsino fishery was however closed in 2020.

Trotlines: A form of longline that has reduced bottom contact and hooks that are at least 2 m above the seafloor and said to reduce impacts on benthic ecosystems (SEAFO, 2017, p. 11).

Gillnets: Gillnets: There are several regions that have prohibited on modified the use of bottom-set gillnets, usually to prevent the high incidental non-selective bycatch and concerns with impacts on lost or abandoned gears. The use of bottom-set gillnets, entangling nets and trammel nets has been prohibited in the high seas of the NE Atlantic Ocean since 2006 in waters deeper than 200 m (NEAFC Rec. III/2006). The use of gillnets in the Southern Ocean has been prohibited since 2010 within the CCAMLR Convention Area (CCAMLR CM 22-04). A further example of gill net restrictions to achieve sustainable management of fish stocks and protection of VMEs occurs in the western North Pacific where “the distance between the footrope of the gill net and sea floor is greater than 70 cm” (NPFC CMM 2018-05 Para. 4(I)).

6. Risk assessment in the EAF context

The EAF is a risk-based management planning process that covers the principles of Sustainable Development, including the human and social elements of sustainability. The EAF forms the basis of modern fisheries management and embraces the precautionary approach.

The EAF Toolbox (FAO, 2018) has been designed to guide users through this process and through each of the four main EAF management planning steps and activities (Figure 8).

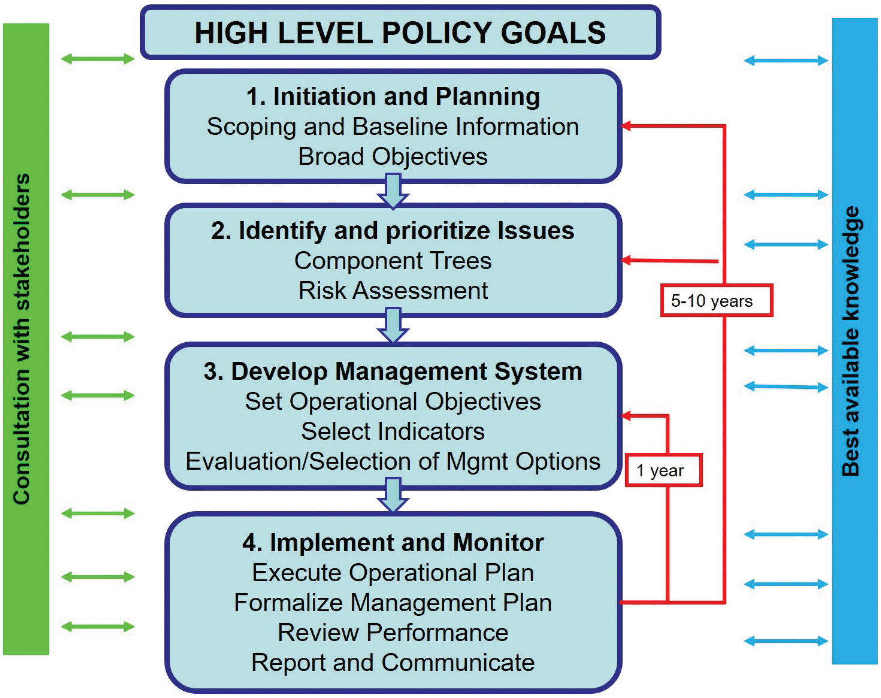

Figure 8. The main EAF management planning steps and activities

The Toolbox helps users decide which tool(s) could be most appropriate for each step given the type of fishery, their resources, and capacity and includes detailed descriptions for the four key steps. Step 2 deals with the identification of assets and issues and ensuring that the most important issues are addressed by direct management intervention. This require determining their relative priority using some form of risk assessment and/or prioritization procedure. Several different risk assessment methods together with guidelines on how they can be applied are presented and are listed in Table 7. These range from qualitative to semi-quantitative and require expert judgement on productivity and susceptibility criteria, and none require any reference or trigger points for actions. Uncertainty is built into most of these methods by increasing the selection of higher risk categories when information is lacking.

Table 7. Ecological risk assessments and possible application to the protection of VME and sponge habitats

Type and source	Information: Fisheries	Information: VMEs	Skill level	Investment/ cost	Example of Type of management action
Expert Judgment or Analysis http://www.fao.org/fishery/eaf-net/eaftool/eaf_tool_27/en	Little to none	Little to none	High	Low	Precautionary VME closures on VME features

Table 7. Continued

Non Formal Risk Categories http://www.fao.org/fishery/eaf-net/eaftool/eaf_tool_10/en	Little to none	Little to none	Low	Low	Probably none. Used more for awareness raising prior to further risk assessments
Qualitative Risk Analysis (consequence × likelihood) http://www.fao.org/fishery/eaf-net/eaftool/eaf_tool_4/en MSC, 2018, p. 73-76 DFO. 2013 http://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/risk-ecolo-risque-eng.htm	Moderate: Distribution of fisheries	Moderate: Distribution of VMEs	Medium	Low to moderate	Identification of fishing footprint and closures of know VMEs
Productivity Susceptibility Assessments (PSA) http://www.fao.org/fishery/eaf-net/eaftool/eaf_tool_55/en MSC, 2018, p. 76-83	Moderate: catch susceptibilities	Moderate: Basic life history characteristics	Hard	Moderate	Identification of fishing footprint and closures of know VMEs. No reference points in method.
Qualitative Risk Analysis (SICA) http://www.fao.org/fishery/eaf-net/eaftool/eaf_tool_23/en MSC, 2018, p. 96-101	Moderate: gear specific impacts	Moderate: Species to ecosystem level	Moderate to hard	Moderate to high	Better assessment of impacts inside and outside of closed areas but still not reference points.
Quantitative Risk Analysis http://www.fao.org/fishery/eaf-net/eaftool/eaf_tool_24/en	Medium to high	Medium to high	High	High	Identification of fishing footprint and closures of know VMEs
Ecological Risk Assessment Framework (ERAF) and risk-based indicators (see section below)	Medium to high	Medium to high			Management measures, indicators and reference points

Guidance on impact assessment (through a risk based approach) is also provided in the FAO DSF Guidelines, para 47 and includes six categories to be taken into consideration when assessing SAIs. Elements of the assessment should include a description of the fishery, best available information on the state of fishery resources including ecosystem, habitats and communities, identification of VMEs known or likely to occur in the area, data and methods used to identify and assess impacts of fishing and gaps in knowledge as well as evaluation of uncertainties, identification and evaluation of the impact including scale and duration as well as cumulative impacts, risk assessment of likely impacts on VMEs and low productivity fishery resources, and finally the proposed mitigation and management measures to be used to prevent SAIs.

7. Ecological risk assessment framework and risk-based indicators

In response to UNGA 61/105, Canada developed and adopted the Policy to Manage the Impacts of Fishing on Sensitive Benthic Areas in 2009. Part of this policy was an Ecological Risk Assessment Framework (ERAF) that is used to determine which fisheries may pose a risk to areas identified as significant benthic areas, including sponge grounds.

The ERAF was further elaborated by Fisheries and Oceans Canada in 2015 for use on marine protected areas in western Canada and, though complex, has the advantage of being better aligned with the sorts of quantitative information that are collected when undertaking fisheries assessments and investigating impacts (O *et al.*, 2015). It must also be noted that this method is most useful when sponges are known to occur, based on a scientific survey or observations of some type. The method was further developed to incorporate indicators that may trigger management responses and the risk analyses became more analytical (DFO, 2015; Thornborough *et al.*, 2016a, b; Hannah, Hornborough and Thiess, 2018). There are two main phases in the ERAF: scoping phase and risk assessment. The scoping phase draws upon stakeholder discussions and literature reviews to identify the inputs to the analysis. The risk assessment identifies the severity of the impacts and allows for them to be prioritised and ranked. The identification of the relevant indicators and reference points to monitor changes in the Significant Ecological Component (SEC), the stressors (or activities generating the stressors), and the SEC-stressor interactions, can be developed after the completion of the risk analysis. Management decisions follow to meet the objectives (Figure 9).

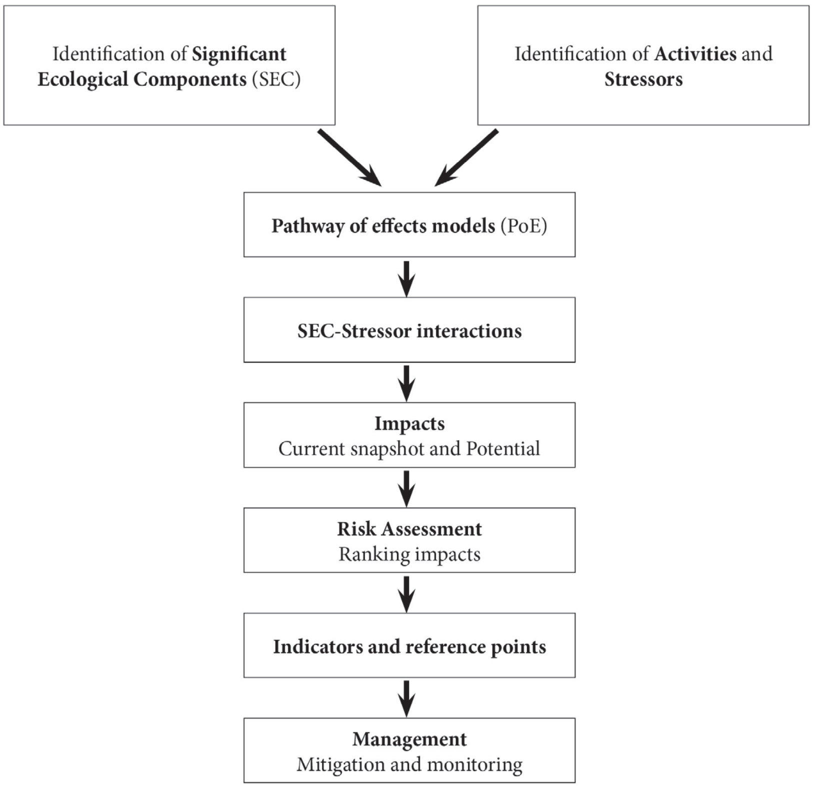

Figure 9. Summary of the processes involved in the ERAF and identification of indicators

7.1 Identification of the elements in the ERAF

The description, conservation and/or fisheries objectivities, and past and current human activities on the site to be assessed should be compiled and examined.

The **Significant Ecological Components** must be selected and can be at the species, habitat or ecosystem level and are typically included in the original descriptions of the site. This list can be extensive, for example, preliminary scoping at the glass sponge site in the Hecate Strait, in Canada's west coast, had 397 species, 3 habitats and 27 ecosystem SECs, though this was reduced to 6 species and 2 habitats SECs after the risk analysis had identified the most important SECs (Hannah, Hornborough and Thiess, 2018). Incorporation of data from SponGES in identifying SECs will play a critical part in the ecological risk assessment process (Figure 10).

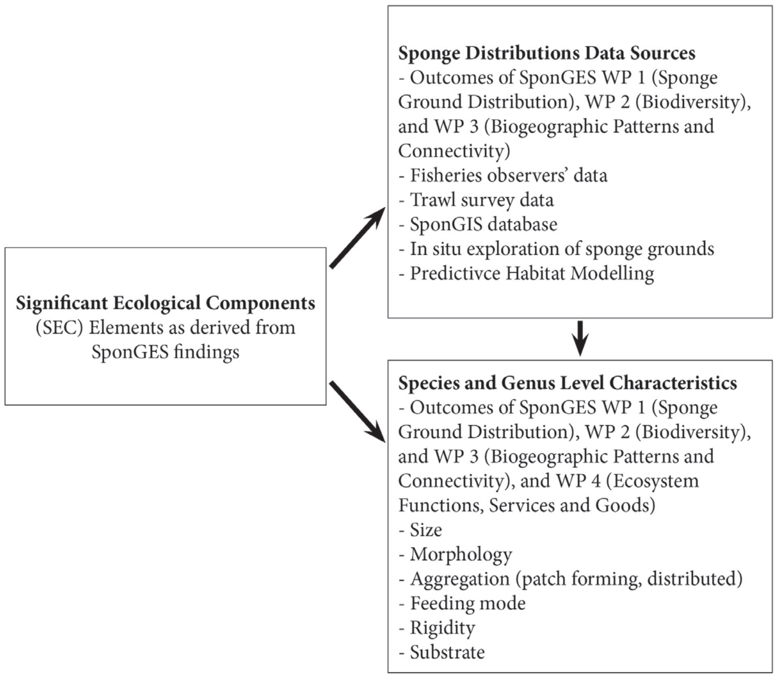

Figure 10. Elements to consider based on SponGES outcomes and identification of significant ecological components.

The human **Activities** occurring on the site are identified and a list of distinct **Stressors** likely to have impacts identified. Again, this list can be extensive but will be reduced following the risk assessment. The stressors may be categorised as current snapshot (predictable and occur regularly) and potential (unpredictable and irregular). The use of **Pathways of Effects** (PoE) models identifies the stressors resulting from the identified activities and the relationships between human activities, associated stressors and their pathway of effect/impact, to give the **SEC-Stressor interactions** and the current snapshot and potential **Impacts**. The list of interactions and impacts can be extensive, but these are prioritised in the **Risk Assessment** and the list reduced to around ten of the most important.

This completes the ERAF and risk assessment, and results in a list of the important SECs, stressors and SEC-Stressor interactions that can be monitored through the use of indicators and assessed against certain reference points.

An example of the SEC-Stressor table for the current snapshot produced for the Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs is shown in Table 8 (from Table 2 in Hannah, Hornborough and Thiess, 2018). This has been simplified following the results of the risk-based analysis to show the higher priority results. The reefs are at 165-240 m depth. The content in the table was chosen specifically to look at and monitor risks and impacts in an MPA. It is seen that the stressors and indicators are specific to the interactions and health of the sponge ground, which is important when the focus is particularly on the ground itself.

Table 8. Indicator suites for current snapshot bottom trawl activities giving SEC-stressor interactions, presented roughly in order of the prioritization results. (from Table 2 of Hannah *et al.*, 2018).

Activity	Stressor	SEC Grouping	SEC	SEC-Stressor interaction indicator	SEC specific indicator	Stressor specific indicator
Bottom trawl	Substrate disturbance (resuspension)	Physical habitat	Glass sponge skeleton matrix (and material contained within)	Abundance (areal extent/proportion) of habitat showing signs of smothering	Abundance (extent and distribution); species richness and diversity associated with the skeleton	Maximum induced increase in suspended sediments; maximum increase in turbidity; substrate composition; maximum potential exposure
		Biotic habitat	Sponge gardens (non-reef building glass sponges and demosponges)	Abundance (areal extent) of habitat showing signs of smothering/stress	Abundance (extent and distribution); health/ condition related to physical smothering; species richness and diversity of associated community	Maximum induced increase in suspended sediments; maximum increase in turbidity; substrate composition; maximum potential exposure
		Reef building glass sponges	*Heterochone calyx* *Aphrocallistes vastus* *Farrea occa* *Rhabdocalyptus dawsoni*	Abundance of colonies showing signs of smothering; number of colonies showing signs of smothering (health and visible smothering)	Health/ condition; abundance	Maximum induced increase in suspended sediments; maximum increase in turbidity
		Bocaccio Rockfish	Bocaccio Rockfish	Change in condition/sub-lethal effects of smothering on Bocaccio Rockfish as a proportion of the population at the reefs	Abundance; biomass; condition factor, k;	Maximum induced increase in suspended sediments; maximum increase in turbidity
		Squat Lobster	*Munida quadrispina*	Change in condition/sub-lethal effects of smothering on *M. quadrispina* as a proportion of the population at the reefs	Abundance/ species density; biomass; health/ condition; species spatial distribution	Maximum induced increase in suspended sediments; maximum increase in turbidity

SEC = significant ecological components

7.2 Application of the ERAF and risk-based indicators to sponge habitats in the North Atlantic

The ERAF and risk-based indicators for deep-sea sponges, where the main threat is from interactions with fisheries, can follow the example given in Table 9 and explained above, particularly for sponge grounds that are identified as VMEs. However, when examining larger areas more generally to investigate provisioning services provided by sponges and how these may be modified by interactions with fisheries using bottom contact fishing gears, then it is often easier to monitor the activities that generate the stressors, rather than monitoring the stressors directly. This is closer to the work of the organisations monitoring bottom fisheries (typically the deep-sea RFMOs). It also provides an overall picture of the interactions throughout the whole area, rather than simply in the area where densities are sufficiently high to form a VME.

Table 9. Modified risk assessment for sponges in the North Atlantic.

<table>
<tr><th>Activity (stressor proxy)</th><th>Sponge SEC grouping and SEC1</th><th>Target fish SEC</th><th>SEC-stressor interaction indicator</th><th>SEC specific indicator</th><th>Activity (Stressor) specific indicator</th></tr>
<tr><td rowspan="4">Bottom trawl
Cod
Redfish
Yellowtail
Greenland halibut
Skate
Shrimp
Long-line
Atlantic halibut
Greenland halibut
Cod
Gillnet
Greenland halibut
Mid-water trawl
Redfish
Pots
Snowcrab</td><td rowspan="4">Deep-sea sponge aggregations

a. Other sponge aggregations
Geodiidae
Ancorinidae
Pachastrellidae

b. Hard-bottom sponge gardens
Axinellidae
Mycalidae
Polymastiidae
Tetillidae

c. Glass sponge communities
Rossellidae
Pheronematidae</td><td rowspan="4"></td><td>Visible injury
Lost fishing gear
Trawl tow tracks</td><td>Abundance estimates
Catch of indicator species
Characteristic of indicator species</td><td>Number of vessels
TAC/Quota
Total effort</td></tr>
<tr><td>Tool:
Ad hoc photo and video images</td><td>Tool:
Habitat surveys
Systematic mapping</td><td>Tool:
VMS
Logbooks</td></tr>
<tr><td>Modelling:
Gear-adjusted-SEC overlay impact assessments (spatial)</td><td>Modelling:
Species distribution models (spatial)</td><td>Modelling:
Gear-specific fishing effort models (spatial)</td></tr>
<tr><td>Limit reference point:
n.a</td><td>Limit reference point:
Catch increase by 50%</td><td>Limit reference point:
Gear-specific activity increased by 75% over baseline in certain areas</td></tr>
</table>

The following simplifying assumptions are made, several of which rely on scientific outcomes of the SponGES project, in their application to risk assessment:

1. The fisheries activities generate the stressors.

2. Fisheries activities are classified according to gear types.

3. Stressor impacts are proportional to the activity for a given gear, but vary among gears (in a manner that is quantifiable).

4. VME indicator taxa are used as the SEC groupings.

5. The SEC grouping provides ecosystem services in proportion to their density/abundance (though these services may not be known).

6. Habitat Suitability Models (HSM)(or similar quantitative distribution models) provide maps of densities of SEC groups (or species).

7. Indicators are chosen to measure and monitor activity change (i.e. a proxy for stressor change).

8. The above fits in to current fisheries regulations and stock assessment practices, with an increased emphasis on monitoring fishing distribution by gear type.

The above simplifications each require further study, especially point 3 to investigate gear-specific impacts on sponges. The detailed stressors identified by Hannah *et al.* (2018) should be used as a starting point. These are:

1. Removal of biological material
2. Strikes
3. Substrate disturbance (crushing)
4. Substrate disturbance (re-suspension)

The overall objective is to use HSM and Species Distribution Models (SDM) to map sponges and sponge VME indicators (SEC groups and SEC) throughout the region and to examine current and cumulative impacts from bottom fishing gears based on increased monitoring and modelling of the spatial distribution of these fisheries. This will identify distribution changes in fishing activity patterns that will help to trigger impact assessments in areas where there has been a significant change in fishing methods or effort. The work being undertaken by the SponGES project will contribute significantly to risk assessments for sponges in the North Atlantic, for a variety of human impacts on the seafloor.

8. Fisheries-induced changes to sponge ecosystem function

Studies on ecosystem functions of marine benthic communities, including sponges, have been summarised by ICES for VME type areas (ICES, 2018), and detailed in sections of this review. Our understanding of these functions is in its infancy and new work and discoveries inform of the importance of these habitats (e.g. NAFO, 2018; ICES, 2018). Recent compilation of information on potential fishing removal of deep-sea sponges in the Northwest Atlantic shows that removal of the sponges would significantly alter ecosystem function, given the role that the sponges play in water filtration, carbon sequestration and nitrogen cycling (Pham et al 2019).

The management of these areas, commencing as early as 2004 in the Northeast Atlantic and 2006 in the Northwest Atlantic, started with identifying areas known or likely to contain VMEs and closuring them to bottom fisheries. The criteria in paragraph 42 of the FAO DSF Fisheries Guidelines (FAO, 2009) was applied collectively and in general terms with the aim to protect marine biodiversity. With increasing commitment to the ecosystem approach, more consideration is being given to protect the functioning of ecosystems by way of the services they provide, and to examine if the closures are ensuring these services continue. This necessitates complex studies within and outside of these closures, which has been assisted by advances in understanding and modelling.

The modelling is important for several reasons. They encourage increased effort to understand the biological processes and functions of the habitats used for input parameter estimation into the models, and they allow for quantitative predictions on species/habitat spatial distributions and associated spatial provisioning services and impacts (e.g., Beazley *et al.*, 2018, Kenchington *et al.*, 2009, 2018; Cogswell *et al.*, 2010; Knudby, Kenchington and Murillo, 2013). This allows for an estimation of the functions provided with the protected closed areas and the proportion that remains at risk and may be lost.

It is clear that removing large biomass of sponges from the deep sea immediately reduces structural complexity and habitat for other benthic species, reduces capacity for carbon and nitrogen cycling as well as removal of micronutrients from the water column, all of which impact the deep-sea ecosystem and the scale of this impact is directly linked to the scale of the biomass removal. As successive stressors impact these ecosystems, it is clear that ecosystem function will be greatly reduced. The changes to ecosystem function are directly linked to recovery rates and timelines. Given that there is relatively little known about reproductive capacity and longevity of most deep-sea sponges, the length of the impact is unknown. Experimental research on the impacts of multiple stressors on deep-sea sponges have begun to yield results that suggest that they are vulnerable to increased sedimentation from mining and ocean warming (Kutti *et al.*, 2015, Scanes *et al.*, 2018, Wurz *et al.* 2018).

9. Strategy to incorporate sponge ground functions into management frameworks

It is currently difficult to provide tipping points or thresholds that may be useful for management purposes, except perhaps an estimation of overlap between various bottom fisheries and the protected areas (NAFO, 2018) and the proportion protected from possible impacts (Beazley *et al.*, 2018). It is likely that protection at a functional level will be achievable within five years, should RFMOs and Contracting Parties commit to protection of areas where sponge grounds are known and likely to occur. There remain data gaps particularly at the species level in terms of reproduction, settling and growth rates; however, results from the SponGES project will fill these gaps for some species. The impact of climate change on deep-sea sponge species is unknown and there is no comprehensive assessment of climate impacts on the North Atlantic deep-sea ecosystem (IPCC, 2019). However, reducing impacts from fishing and other industrial activities that take place on the sea floor, including oil and gas impacts (DFO, 2019) and deep seabed mining (SPC, 2017, Washburn *et al.*, 2019), may improve general ecosystem health and resilience of sponge grounds to any predicted climate impacts in the long term.

Hannah *et al.* (2018) provided some indicators applicable to MPAs to identify if impacts were occurring. These were metrics like abundance (numbers, biomass), diversity, visible injury, and condition index. Whereas this may be possible at a few special sites, the cost of the required monitoring at the depth of deep-sea sponge grounds is likely to be excessive and unobtainable in most cases. Current information on deep-sea sponges, species compositions and community structure can be used to determine relative vulnerability. Traits-based analysis is increasingly being used to better understand the impacts of human activity on benthic species (Bolam and Eggleton 2014, Bolam *et al.* 2017), and will likely prove useful in assessing the relative vulnerability of sponge species and populations to the impacts of fishing.

Incorporation of sponge ground functions into the scientific advice will assist managers in adopting measures to protect the sponge grounds and preserve the functions. Research over the past two decades has greatly enhanced knowledge of these areas. Implementation of the precautionary approach and limiting fishing activity in areas where sponges are known and likely to occur will provide maximum probability that sponge ecosystem function is maintained.

Detailed monitoring of past, current and future fishing activities, with regards to their impact on sponges, should be integrated into ecosystem-based fisheries management. This should be combined with selective case studies on smaller benthic areas and species concentrations. The monitoring of the fisheries has the additional benefit of providing information useful for fish stock management. The important parameters to monitor are:

- The locations of the bottom fishing.
- The gear deployed and associate fine scale spatial effort.
- Efficacy of fisheries observer program.
- Resolution and reporting of fisheries dependent data (i.e. haul by haul, or trip basis)

- Applications of risk assessment.
- Models to identify significant changes in fishing pattern, using VMS or logbook data when available.
- Appropriate VME indicator threshold levels.
- Effective application of encounter protocols and move on rules.
- Reporting of encounters of indicator species.
- Appropriate and adaptive mitigation response, including establishment of closed areas.
- Improvements in gear design to reduce impacts.
- Incorporation of new technologies that better monitor impacts (e.g. underwater trawl-mounted camera systems).

Mitigating the impacts of monitoring, which has largely been done through destructive sampling by research trawl surveys will have to be considered as well, with an investment and preference for non-destructive sampling.

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SponGES is a research and innovation project funded under the H2020 Blue Growth initiative. It aims at “Improving the preservation and sustainable exploitation of Atlantic marine ecosystems” and at developing an integrated ecosystem-based approach to preserve and sustainably use deep-sea sponge ecosystems of the North Atlantic. Reducing the impacts of deep-sea bottom fishing in the high seas on these ecosystems is an important element of an ecosystem-based approach to fisheries management. States and Regional Fisheries Management Organizations (RFMOs) have implemented a variety of measures to avoid and mitigate impacts of deep-sea bottom fishing on sponges, and have established methods for ecological risk assessment. Specific information to inform these risk assessments is often lacking but SponGES spurred unprecedented research on deep sea sponges in the North Atlantic, resulting in improved knowledge and understanding of sponge distribution, ecological function, impacts of human activities and climate change, role in the deep sea ecosystem, and their potential economic contributions through biotechnological components.

This publication serves as a comprehensive review of existing governance mechanisms to protect sponge ecosystem function in the deep sea. It also presents appropriate elements to be included in an ecological risk assessment of anthropogenic stressors, and contributes to producing a strategy to incorporate sponge ground functions into management frameworks.

SponGES

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