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SC WORKING GROUP ON ECOSYSTEM SCIENCE AND ASSESSMENT – NOVEMBER 2020

Report of the 13th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA)

By WebEx

17-26 November 2020

Contents

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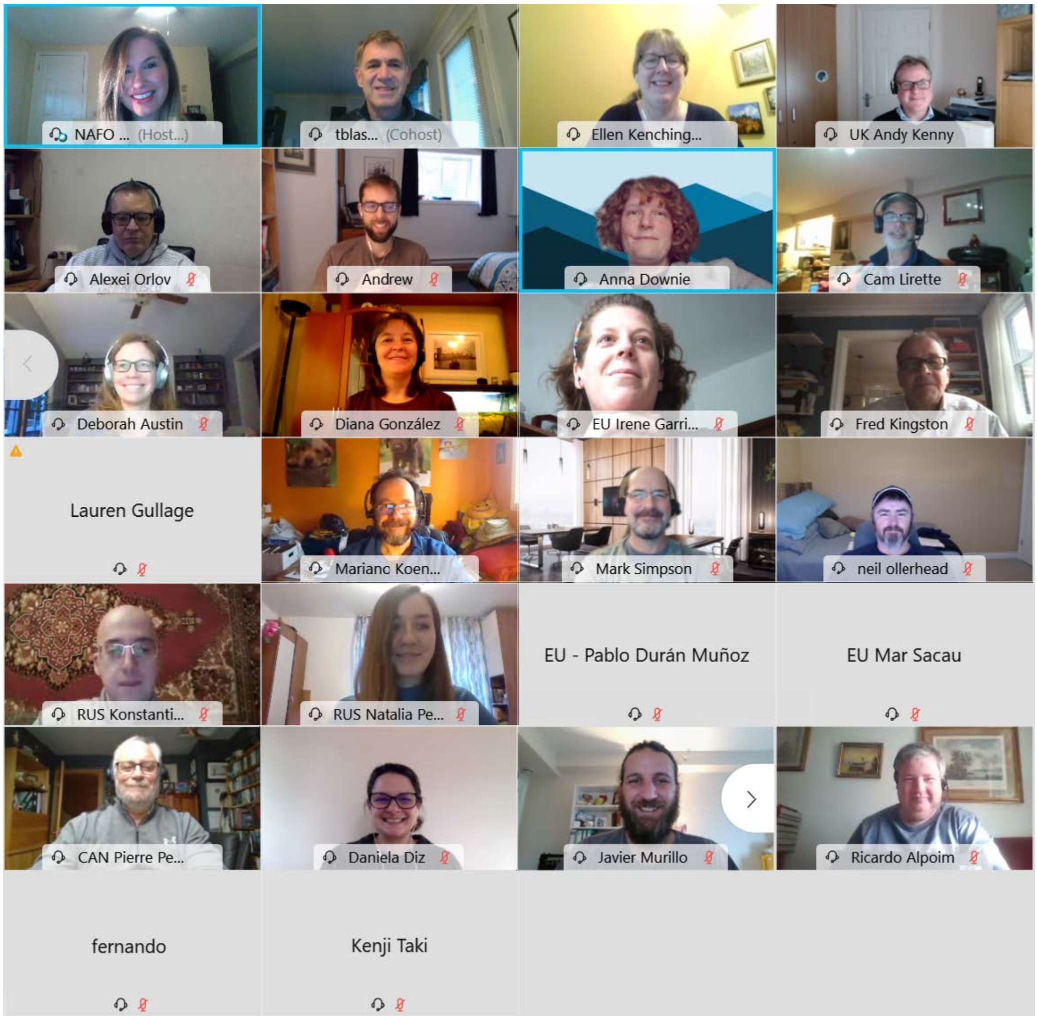

WG-ESA Meeting Participants

17-26 November 2020

From left to right:

First row: Dayna Bell MacCallum, Tom Blasdale, Ellen Kenchington, Andrew Kenny (co-Chair)

Second row: Alexei Orlov, Andrew Cuff, Anna Downie, Camille Lirette

Third row: Deborah Austin, Diana González-Troncoso, Irene Garrido, Fred Kingston

Fourth row: Lauren Gullage, Mariano Koen-Alonso, Mark Simpson, Neil Ollerhead

Fifth row: Konstantin Fomin, Natalya Petukhova, Pablo Durán Muñoz, Mar Sacau-Cuadrado

Sixth row: Pierre Pepin (co-Chair), Daniela Diz, F. Javier Murillo Perez, Ricardo Alpoim

Seventh row: Fernando González-Costas, Kenji Taki

Missing from photo: Susanna Fuller, Barbara Neves, Ken Lee, Vonda Wareham-Hayes, Shaungqiang Wang, Garry Stenson, Carmen Fernández, Cristina Ribeiro, Temur Tairov, Elizabethann Mencher, Katherine Sosebee, Ricardo Federizon

Report of the SC Working Group on Ecosystem Science and Assessment (WG-ESA)

17-26 November 2020

1. Opening by the co-Chairs

The meeting was opened at 08:00 hours (Halifax Time) on 17 November 2020. The co-Chairs, Andrew Kenny (UK) and Pierre Pepin (Canada) welcomed participants.

Andrew Kenny presented the detailed agenda and outlined the work plan for the meeting as well as the terms of reference and the Commission requests relevant to the working group. ToR and commission requests are presented in the Agenda in Annexes 1. A list of participants is presented in Appendix 2.

2. Appointment of Rapporteur

The Scientific Council Coordinator was appointed as rapporteur.

3. Adoption of Agenda

The agenda and detailed agenda were adopted as circulated.

4. Update on VME species from surveys

ToR 1.1.

a) Update on VME indicator species data and VME indicator species distribution from EU-Spain and Portugal Groundfish Surveys and Fall Canadian surveys.

During the 13th NAFO Working Group on Ecosystem Science and Assessment (WG-ESA) virtual meeting new preliminary data on deep-water corals and sponges were presented from the 2020 EU-Spain and Portugal and fall Canadian bottom trawl groundfish surveys. The data was made available to the NAFO WG-ESA to improve mapping of Vulnerable Marine Ecosystem (VME) species in the NAFO Regulatory Area (Divs. 3LMNO).

As a result of the pandemic during 2020, R/V Vizconde de Eza only carried out one survey in Division 3M (184 tows). Similarly, no Canadian surveys took place during the spring of 2020 for the same reason, and only the Canadian data for the 2019 fall survey were available (71 tows).

Distribution maps (with significant and non-significant catches) for large Gorgonian Corals, Small Gorgonian Corals, Sea Pens, Black Corals, *Boltenia ovifera* and Large-sized Sponges were presented for both surveys. Detailed information and illustrative maps are in Sacau *et al*. (2020).

Table 4.1 presents a summary of deep-water corals and sponges records for the NRA from 2020 EU-Spain and Portugal survey and 2019 fall Canadian surveys.

Table 4.1. Deep-water corals and sponges records for the NRA from 2020 EU-Spain and Portugal survey and 2019 Fall Canadian surveys.

EU-Spain and Portugal data 2020	Presence Significant and Non-Significant (# of tows)	Total Tows (% of tows)	Significant Concentrations (# of tows)	Significant Concentrations (% of tows)	Significant Concentrations inside KDE corresponding polygon
Large-sized Sponges	47	25.5%	0	0%	0
Large Gorgonian Corals	2	1%	0	0%	0
Small Gorgonian Corals	15	8.15%	0	0%	0
Sea Pens	59	32%	0	0%	0
Canadian data 2019 (Fall)					
Large-sized Sponges	35	49%	0	0%	0
Large Gorgonian Corals	2	2.8%	0	0%	0
Sea Pens	10	14%	0	0%	0
Boltenia ovifera	7	9.9%	4	5.6%	4

References

Sacau, M., Neves, B.M. and Durán-Muñoz, P. New preliminary data on VME encounters in NRA (Div. 3M) from EU-Spain and Portugal Groundfish Surveys (2020) and Canadian surveys. NAFO SCR Doc. 20/070. Serial No. N7146. Dartmouth, NS.

5. Up-date list of taxa Annex I.E NCEM

ToR 1.2, Commission Request 7

The Commission requests that Scientific Council review the proposed revisions to Annex I.E, Part VI as reflected in COM/SC WG –EAFFM WP 18-01, for consistency with the taxa list annexed to the VME guide and recommend updates as necessary.

WG-ESA recommends the following changes to Annex I.E, Part VI to reflect current correct taxonomic nomenclature, to correct spelling errors in previous versions and add three letter ASFIS codes where they are available.

VI. List of VME Indicator Species

Common Name and FAO ASFIS 3- ALPHA CODE	Taxon	Family	FAO ASFIS 3-ALPHA CODE
Large-Sized Sponges (PFR - Porifera)	*Asconema foliatum*	Rossellidae	ZBA
	Aphrocallistes beatrix	Aphrocallistidae	
	Asbestopluma (Asbestopluma) ruetzleri	Cladorhizidae	ZAB (Asbestopluma)
	Axinella sp.	Axinellidae	
	Chondrocladia grandis	Cladorhizidae	ZHD (Chondrocladia)
	Cladorhiza abyssicola	Cladorhizidae	ZCH (Cladorhiza)
	Cladorhiza kenchingtonae	Cladorhizidae	ZCH (Cladorhiza)
	Craniella spp.	Tetillidae	ZCS (Craniella spp.)
	Dictyaulus romani	Euplectellidae	ZDY (Dictyaulus)
	Esperiopsis villosa	Esperiopsidae	ZEW
	Forcepia spp.	Coelosphaeridae	ZFR
	Geodia barretti[1]	Geodiidae	
	Geodia macandrewii	Geodiidae	
	Geodia parva	Geodiidae	
	Geodia phlegraei	Geodiidae	
	Haliclona sp.	Chalinidae	ZHL
	Iophon piceum	Acarnidae	WJP
	Isodictya palmata	Isodictyidae	
	Lissodendoryx (Lissodendoryx) complicata	Coelosphaeridae	ZDD
	Mycale (Mycale) lingua	Mycalidae	YHL (Mycale lingua)[2]
	Mycale (Mycale) loveni	Mycalidae	
	Phakellia sp.	Axinellidae	
	Polymastia spp.	Polymastiidae	ZPY
	Stelletta normani	Ancorinidae	WSX (Stelletta)
	Stelletta tuberosa	Ancorinidae	WSX (Stelletta)
	Stryphnus fortis	Ancorinidae	WPH
	Thenea muricata	Pachastrellidae	ZTH (Thenea)
	Thenea valdiviae	Pachastrellidae	ZTH (Thenea)
	Weberella bursa	Polymastiidae	ZWB (Weberella spp.)[3]

1 Spelling correction
2 Code in 2020 ASFIS list.
3 Code in 2020 ASFIS list.

Common Name and FAO ASFIS 3- ALPHA CODE	Taxon	Family	FAO ASFIS 3-ALPHA CODE
Stony Corals (CSS - Scleractinia)	*Enallopsammia rostrata*	Dendrophylliidae	FEY
	Lophelia pertusa	Caryophylliidae	LWS
	Madrepora oculate	Oculinidae	MVI
	Solenosmilia variabilis	Caryophylliidae	RZT
Black corals (AQZ-Antipatharia)	*Stichopathes* sp.	Antipathidae	QYX
	Leiopathes cf. *expansa*	Leiopathidae	
	Leiopathes sp.	Leiopathidae	
	Plumapathes sp.	Myriopathidae	
	Bathypathes cf. *patula*	Schizopathidae	
	Parantipathes sp.	Schizopathidae	
	Stauropathes arctica	Schizopathidae	SQW
	Stauropathes cf. *punctata*	Schizopathidae	
	Telopathes magnus	Schizopathidae	
Small Gorgonians (GGW)	*Acanella arbuscula*	Isididae	KQL (Acanella)
	Anthothela grandiflora	Anthothelidae	WAG
	Chrysogorgia sp.	Chrysogorgiidae	FHX
	Metallogorgia melanotrichos	Chrysogorgiidae	QFY (Chrysogorgiidae)[4]
	Narella laxa	Primnoidae	QON (Primnoidae)[5]
	Radicipes gracilis	Chrysogorgiidae	CZN
	Swiftia sp.	Plexauridae	
Large Gorgonians (GGW)	*Acanthogorgia armata*	Acanthogorgiidae	AZC
	Calyptrophora sp.	Primnoidae	QON (Primnoidae)[6]
	Hemicorallium bathyrubrum[7]	Coralliidae	COR (Corallium)
	Hemicorallium bayeri[8]	Coralliidae	COR (Corallium)
	Iridogorgia sp.	Chrysogorgiidae	QFY (Chrysogorgiidae) [9]
	Keratoisis cf. *siemensii*	Isididae	IQO (Isididae)[10]

4 Code in 2020 ASFIS list.
5 Code in 2020 ASFIS list.
6 Code in 2020 ASFIS list.
7 Name changed in taxonomic revision
8 Name changed in taxonomic revision
9 Code in the 2020 ASFIS list.
10 Code in the 2020 ASFIS list.

Common Name and FAO ASFIS 3- ALPHA CODE	Taxon	Family	FAO ASFIS 3-ALPHA CODE
	Keratoisis grayi	Isididae	IQO (Isididae) [11]
	Lepidisis sp.	Isididae	QFX (Lepidisis)
	Paragorgia arborea	Paragorgiidae	BFU
	Paragorgia johnsoni	Paragorgiidae	BFV
	Paramuricea grandis	Plexauridae	PZL (Paramuricea)
	Paramuricea placomus	Plexauridae	PZL (Paramuricea)
	Paramuricea spp.	Plexauridae	PZL (Paramuricea)
	Parastenella atlantica	Primnoidae	QON (Primnoidae) [12]
	Placogorgia sp.	Plexauridae	
	Placogorgia terceira	Plexauridae	
	Primnoa resedaeformis	Primnoidae	QOE
	Thouarella (Euthouarella) grasshoffi	Primnoidae	QON (Primnoidae) [13]
Sea Pens (NTW – Pennatulacea)	*Anthoptilum grandiflorum*	Anthoptilidae	AJG (Anthoptilum)
	Distichoptilum gracile	Protoptilidae	WDG
	Funiculina quadrangularis	Funiculinidae	FQJ
	Halipteris cf. *christii*	Halipteridae	ZHX (Halipteris)
	Halipteris finmarchica	Halipteridae	HFM
	Halipteris sp.	Halipteridae	ZHX (Halipteris)
	Kophobelemnon stelliferum	Kophobelemnidae	KVF
	Pennatula aculeata	Pennatulidae	QAC
	Ptilella spp.[14]	Pennatulidae	
	Pennatula sp.	Pennatulidae	
	Protoptilum carpenteri	Protoptilidae	
	Umbellula lindahli	Umbellulidae	OJZ (Ombellula spp) [15]
	Virgularia mirabilis	Virgulariidae	
Tube-Dwelling Anemones	*Pachycerianthus borealis*	Cerianthidae	WQB

11 Code in the 2020 ASFIS list.
12 Code in the 2020 ASFIS list.
13 Code in the 2020 ASFIS list.
14 Name change in taxonomic revision
15 Listed in the 2020 ASFIS code list as Ombellula which is a spelling variant. Umbellula is correct but they are the same genus (synonyms)

Common Name and FAO ASFIS 3- ALPHA CODE	Taxon	Family	FAO ASFIS 3-ALPHA CODE
Erect Bryozoans (BZN – Bryozoa)	*Eucratea loricata*	Eucrateidae	WEL
Sea Lilies (CWD – Crinoidea)	*Conocrinus lofotensis*	Bourgueticrinidae	WCF
	Gephyrocrinus grimaldii	Hyocrinidae	
	Trichometra cubensis	Antedonidae	
Sea Squirts (SSX – Ascidiacea)	*Boltenia ovifera*	Pyuridae	WBO
	Halocynthia aurantium	Pyuridae	
Unlikely to be observed in trawls; *in situ* observations only:			
Large xenophyophores	*Syringammina* sp.	Syringamminidae	

6. Up-date seabird, mammals, and turtle information

ToR 1.3 Commission Request 17

The Commission requests the Scientific Council to provide information to the Commission at its next annual meeting on sea turtles, sea birds, and marine mammals that are present in NAFO Regulatory Area based on available data.

Data on the presence and abundance of marine mammals and turtles in the NRA are obtained from dedicated sighting surveys, opportunistic sightings, acoustic recorders and satellite telemetry studies. However, the amount of survey data available from the NRA is limited as a result of difficulties reaching the area with survey aircraft while opportunistic sightings reflect the distribution of observers rather than the distribution of animals. Marine mammal observers during the Spanish groundfish survey (Div. 3L) and on the fishing fleet (Div. 3LMNO) have provided some information on cetacean species presence in the NRA, based on sightings from an opportunistic sampling (Roman-Marcote *et al.,* 2019; 2020). The deployment of acoustic recorders in offshore areas is recent and not fully analyzed. These instruments provide information on the presence or absence of individual species although preliminary analyses have indicated that identification of marine mammals present is difficult because of the high level of background noise from vessels and seismic activity.

Being highly mobile, marine mammals and turtles utilize large areas, often moving across the North Atlantic or from the Caribbean to the Arctic. Most species are seasonal migrants although some individuals may remain year-round, particularly in the warmer waters near the Tail of the Grand Banks. Many of the cetaceans and turtles winter in southern waters, but summer on the Grand Banks and in the NRA while others such as harp and hooded seals summer in the Arctic and winter on the Newfoundland Shelf and Grand Banks.

The Grand Banks are a transition zone with both Arctic and temperate species occurring. As a result, approximately 25 cetacean and seven (7) pinniped species are present in the NAFO Convention Area. Of these, five (5) pinnipeds (walrus, and ring, bearded, harbour, and grey seals) and two (2) cetaceans (beluga and narwhal) are mainly observed in nearshore waters and so unlikely to occur in the NRA. Many of the remaining species, such as minke, humpback and killer whales, and most of the small cetaceans and harbour porpoise, are widely distributed across the continental shelf, including the NRA. They are also occasionally sighted in the deep water off the shelf edge. Sperm whales are commonly reported in NRA in both the opportunistic sightings database and by Spanish observers and groundfish surveys. Fin whales are also widely spread throughout the convention area, although a habitat suitability model identified the Nose and Tail of the Grand Banks, Flemish Pass and Orphan Basin areas as important habitat during the spring and summer. The southern edge of the

Grand Banks was also identified as important habitat for the endangered Northwest Atlantic blue whale population.

Some species are most commonly found along the continental slope. Long finned pilot whale were reported in the Flemish Pass (Div. 3L) by the Spanish groundfish surveys. Beaked whales (Family Ziphiidae) are a poorly understood group that inhabit offshore slope habitats and appear to be particularly sensitive to sound. The best known of this family is the Northern Bottlenose Whale which occurs along the edge of the continental shelf from Davis Strait to the Scotian shelf. A habitat suitability model indicates that the area from the Nose of the Banks, Orphan Basin to Flemish Pass and Flemish Cap are particularly important for this species. The species is commonly reported in Div. 3L (Román-Marcote *et al.,* 2020).

There are considerable data available on the movements of harp and hooded seals based on satellite telemetry studies. Both species feed in the NRA prior to, and after, the pupping period in March. Harp seals utilize the continental shelf, particularly the Nose of the Banks, while hooded seals are common along the slope edges of the Flemish Pass and Flemish Cap. These are important feeding areas for both species.

Harp seals are the most abundant marine mammal in the North Atlantic. After two decades of being relatively stable, the NW Atlantic population is currently estimated to have increased over the past five (5) years to 7.6 million. Hooded seals were last assessed in 2006 at 587 000. Less is known about abundance of cetaceans; only two large scale surveys have been carried out that covered the entirety of Canadian Atlantic waters, one in 2007 and the other in 2016. The estimates of abundance of the main species varied among surveys and could not be accounted for by population growth, suggesting a change in distribution from the earlier to the later survey. In 2016, abundance of minke whales, humpback whales and fin whales in Newfoundland and Labrador waters were estimated to be 12 000, 8 400 and 2 200, respectively. The most abundant cetacean was white-beaked dolphins (530,500). Because of the lack of long-term data, trends in abundance of almost all of the cetacean species are unknown.

Three species of sea turtles, loggerhead, green and leatherback, have been reported in the NRA. However, only leatherback turtles occur regularly. They migrate from South America to feed on jellyfish in the NAFO Convention Area each year, and occur in the Northwest Atlantic primarily during the late summer and early fall when water temperatures reach a maximum. A habitat suitability model based on data from the 2016 megafauna survey did not extend to the NRA but indicated that suitable habitat for leatherback turtles extended across the Grand Banks to both the Nose and Tail.

Many of the species included in this summary have been reported caught in fishing gear in the NRA and the Convention Area but bycatch rates are unknown.

Data on the presence of seabirds in the NAFO Regulatory Area (NRA) can also be obtained from scientific survey, opportunistic sightings, acoustic recorders and satellite telemetry studies and also from bycatch reporting and light-level geolocators. There are not many dedicated surveys conducted in the NRA specifically for seabirds and most visual surveying is done terrestrially on nesting sites or nearshore habitats. There are some opportunistic and citizen science reporting of seabirds in coastal waters, including the NRA, but these data are sparse and have limited use beyond determining presence/absence.

The summer seabird community and the distribution of seabirds in the Flemish Cap (Div. 3M) were described by Leyenda and Munilla (2002), based on data from EU groundfish surveys. Eight species were counted within census transects. Over 70% of seabirds were great shearwaters (*Ardenna gravis*), followed by northern fulmars (*Fulmarus glacialis*) with 17.1% of the seabirds recorded. Seabird abundance and seabird species richness were not evenly distributed across the Flemish Cap but seemed to concentrate at the edges of the southern half of the study area. Both species are also the most frequent seabirds reported in the Flemish Pass (Div. 3L) by the Spanish groundfish surveys (2012-2019), although abundance is not recorded on this survey platform (Roman-Marcote *et al.,* 2020). On the Flemish Pass survey thirteen seabird species were sighted.

A majority of the information available on the seabird species using the NRA comes from light-level geolocators or other small, lightweight tags allowing bird migrations to be recorded. There are an abundance of seabird tracking studies conducted in the Atlantic that indicate the NRA is being used by seabirds. These studies are helping to delineate seabird species' seasonal use patterns, migration routes and time spent at sea.

Seabirds can be highly migratory and travel great distances between foraging and nesting areas; for example the Arctic Tern migrates between Arctic and Antarctic waters. As such a majority of the species found in the NRA are only in the area seasonally, however some species are found in the area year-round.

An initial literature review indicates a total of 58 species have been found to use the NCA and of those 31 species have more geographically specific data indicating they use the NRA. Families Laridae (terns and gulls) and Procellariidae (petrels and shearwaters) make up 18 of the 31 species observed in the NRA (Table 6.1).

Table 6.1. Seabirds known to use the NAFO Regulatory Area (NRA) by Order and Family.

Common name	*Latin name*	Order: family
Atlantic Puffin	*Fratercula arctica*	CHARADRIIFORMES: Alcidae
Common Murre	*Uria aalge*	CHARADRIIFORMES: Alcidae
Dovekies (little auks)	*Alle alle*	CHARADRIIFORMES: Alcidae
Thick-billed Murre	*Uria lomvia*	CHARADRIIFORMES: Alcidae
Arctic Tern	*Sterna paradisaea*	CHARADRIIFORMES: Laridae
Black-legged Kittiwake	*Rissa tridactyla*	CHARADRIIFORMES: Laridae
Common Tern	*Sterna hirundo*	CHARADRIIFORMES: Laridae
Glaucous Gull	*Larus hyperboreus*	CHARADRIIFORMES: Laridae
Great Black-backed Gull	*Larus marinus*	CHARADRIIFORMES: Laridae
Lesser Black-backed Gull	*Larus fuscus*	CHARADRIIFORMES: Laridae
Ivory Gull	*Pagophila eburnea*	CHARADRIIFORMES: Laridae
Iceland Gull	*Larus glaucoides*	CHARADRIIFORMES: Laridae
Sabine's Gull	*Xema sabini*	CHARADRIIFORMES: Laridae
Red-necked Phalarope	*Phalaropus lobatus*	CHARADRIIFORMES: Scolopacidae
Great Skua	*Stercorarius skua*	CHARADRIIFORMES: Stercorariidae
Long-tailed Jaeger (skua)	*Stercorarius longicaudus*	CHARADRIIFORMES: Stercorariidae
Parasitic Jaeger	*Stercorarius parasiticus*	CHARADRIIFORMES: Stercorariidae
Pomarine Jaeger	*Stercorarius pomarinus*	CHARADRIIFORMES: Stercorariidae
South Polar Skua	*Stercorarius maccormicki*	CHARADRIIFORMES: Stercorariidae
Leach's Storm-petrel	*Oceanodroma leucorhoa*	PROCELLARIIFORMES: Hydrobatidae
Bermuda Petrel	*Pterodroma cahow*	PROCELLARIIFORMES: Procellariidae
Black-capped Petrel	*Pterodroma hasitata*	PROCELLARIIFORMES: Procellariidae
Cory's Shearwater	*Calonectriz diomedea*	PROCELLARIIFORMES: Procellariidae
Desertas Petrel	*Pterodroma deserta*	PROCELLARIIFORMES: Procellariidae
Great Shearwater	*Ardenna gravis*	PROCELLARIIFORMES: Procellariidae
Manx Shearwater	*Puffinus puffinus*	PROCELLARIIFORMES: Procellariidae
Northern Fulmar	*Fulmarus glacialis*	PROCELLARIIFORMES: Procellariidae
Sooty Shearwater	*Ardenna grisea*	PROCELLARIIFORMES: Procellariidae
Trindade Petrel	*Pterodroma arminjoniana*	PROCELLARIIFORMES: Procellariidae
Wilson's Storm Petrel	*Oceanites oceanicus*	PROCELLARIIFORMES: Oceanitidae
Northern Gannet	*Morus bassanus*	SULIFORMES: Sulidae

References

Leyenda, P. M., and I. M. Rumbao. (2005). The summer seabird community of the Flemish Cap in 2002. J. Northw. Atl. Fish. Sci., 37: 47-52. doi:10.2960/J.v37.m554

Román-Marcote, E., Durán Muñoz, P. and Sacau, M. (2019) Preliminary information from EU-Spain regarding Commision request #18. Oral presentation. 12th NAFO Working Group on Ecosystem Science Assessment. 18-28 November 2019. NAFO Headquarters. Dartmouth, Nova Scotia, Canada.

Román-Marcote, E., Durán Muñoz, P. and Sacau, M. (2020). Preliminary information from EU-Spain surveys in Div 3L regarding Commission request #18: "Provide information to the Commission at its next annual meeting on sea turtles, seabirds, and marine mammals that are present in NRA based on available data". NAFO SCR Doc. 20/023 (Rev.) Serial No. N7069, 8 pp.

7. Assessment of Bottom fisheries

Commission Request 6

The Commission requests that Scientific Council, in preparation of the re-assessment of NAFO bottom fisheries in 2021 and discussion on VME fishery closures:

i. Assess the overlap of NAFO fisheries with VME to evaluate fishery specific impacts in addition to the cumulative impacts for NRA fisheries;
ii. Consider clearer objective ranking processes and options for objective weighting criteria for the overall assessment of significant adverse impacts and the risk of future adverse impacts;
iii. Maintain efforts to assess all of the six FAO criteria including the three FAO functional SAI criteria which could not be evaluated in the current assessment.
iv. Provide input and analysis of potential management options, with the goal of supporting meaningful and effective discussions between scientists and managers at the 2021 WG-EAFFM meeting;
v. Continue to work on the VME indicator species as listed in Annex IE, Section VI to prepare for the next assessment.

Introduction

i) Policy Background

Under the UN Convention on the Law of the Sea (UNCLOS), State Parties have an obligation to conduct environmental impact assessments when they have reasonable grounds for believing that planned activities under their jurisdiction or control may cause significant and harmful changes to the marine environment, and make these reports publicly available.[16] The 1995 UN Fish Stocks Agreement (UNFSA) – an implementing agreement to UNCLOS – in giving effect to the duty to cooperate under UNCLOS and in order to conserve and manage straddling and highly migratory fish stocks, obliges coastal State Parties and Parties fishing on the high seas to "**assess the impacts of fishing, other human activities and environmental factors** on target stocks and species belonging to the same ecosystem or associated with or dependent upon the target stocks".[17] UNFSA also provides for the obligation to protect biodiversity,[18] a duty that is also reflected in the NAFO Convention.[19]

The NAFO Convention recalls the relevant provisions of UNCLOS and UNFSA and takes into account relevant FAO instruments.[20] More specifically, the NAFO Convention is to be interpreted and applied consistently with UNCLOS and UNFSA.[21] Furthermore, the Convention commits its Parties to "apply an ecosystem approach to fisheries[22] management in the Northwest Atlantic that includes safeguarding the marine environment, conserving its marine biodiversity, **minimizing the risk of long term or irreversible adverse effects of fishing activities**, and taking account of the relationship between all components of the ecosystem"[23] (emphasis added). Article III of the Convention obliges its Contracting Parties to take due account of the fishing

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16 UNCLOS, Arts. 205-206.
17 UNFSA, Art 5 (d).
18 UNFSA, Art. 5(g).
19 Convention on Cooperation in the Northwest Atlantic Fisheries, 2017 amendment, (NAFO Convention), Art. III (e).
20 NAFO Convention. See 2nd and 3rd preambular paragraphs.
21 NAFO Convention, Art. XXI (2).
22 Technical guidance on the implementation of the ecosystem approach to fisheries is elaborated under the FAO*, The* ecosystem *approach to fisheries. FAO Technical Guidelines for Responsible Fisheries*. No. 4, Suppl. 2. Rome, FAO. 2003. 112 p.; See also FAO*, The ecosystem approach to fisheries. FAO Technical Guidelines for Responsible Fisheries.* No. 4, Suppl. 2, Add. 2. Rome, FAO. 2009. 88p.
23 NAFO Convention, 8th preambular para. See also Article II, which states the Convention's objective to ensure the long-term conservation and sustainable use of the fishing resources in the Convention Area by safeguarding the marine ecosystems in which these resources are found.

impacts on other species and marine ecosystems by **adopting measures to minimise harmful impacts on living marine resources and ecosystems.**[24]

Further guidance on how to avoid significant adverse impacts (SAIs) on Vulnerable Marine Ecosystems (VMEs) was adopted under the 2008 FAO Deep-sea Fisheries Guidelines[25] in response to the UN General Assembly (UNGA) resolution 61/105 (2006), which called upon RFMOs to assess, based on the best available science, whether individual bottom fishing activities would have SAIs on VMEs and to prevent any such impacts or not be authorised to proceed.[26] The FAO Guidelines defines SAI as those impacts that compromise ecosystem integrity (structure and function) in a way that impairs the ability of affected populations to replace themselves, or that degrades the long-term productivity of habitats, or causes significant loss of species richness, habitat or community types.[27] To determine the scale and significance of the impact, the Guidelines suggest six factors to be considered: (i) the intensity or severity of the impact at the specific site; (ii) the spatial extent of the impact in relation to the availability of the habitat type being affected; (iii) the sensitivity or vulnerability of the ecosystem; (iv) the ability of the ecosystem to recover and the rate of recovery; (v) the extent to which ecosystem functions may be altered; and (vi) the timing and duration of the impact in relation to the period in which a species needs the habitat during one or more of its life-history stages.[28]

The determination of whether the impact is temporary or long-term should be done on a case-by-case basis, considering the specific features of the populations and ecosystems.[29] While the Guidelines refers to an indicative time-frame of 5-20 years recovery period, it also underscores that "both the duration and frequency at which an impact is repeated should be considered".[30] In cases where the period between the expected disturbance is shorter than the recovery time, the impact should be considered more than temporary.[31] The Guidelines also state that in cases of limited information, States and RFMOs should apply the precautionary approach regarding the nature and duration of the impacts.[32] The FAO Guidelines elaborates further on the need to apply the precautionary approach in governance and management of deep sea fishing (DSF) by affirming that "States and RFMOs/As should ensure that measures for the sustainable conservation and management of DSFs, the prevention of significant adverse impacts on VMEs and protection of the marine biodiversity that these ecosystems contain are adopted and implemented consistent with the precautionary approach".[33]In reference to the precautionary approach, Principle 15 of the 1992 Rio Declaration states that where there are threats of serious damage, "the lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation".[34] The Fish Stocks Agreement[35] and the NAFO Convention[36] also call for the application of the precautionary approach in cases of scientific uncertainty.

In posterior reviews of the implementation of the VME-related paragraphs of the UNGA resolution 61/105, the UNGA[37] called upon States and RFMOs to, *inter alia*:[38]

(i) Identify areas where VMEs occur or are likely to occur and assess SAIs;

24 NAFO Convention, Art. III (d).
25 FAO, *International Guidelines for the Management of Deep-sea Fisheries in the High Seas* (Rome: FAO, 2009). (FAO Deep-sea Guidelines)
26 UNGA Resolution 61/105 (2006), para 83 (a).
27 FAO Deep-sea Guidelines, para 17.
28 FAO Deep-sea Guidelines, para 18.
29 FAO Deep-sea Guidelines, para 19.
30 FAO Deep-sea Guidelines, para 20.
31 FAO Deep-sea Guidelines, para 20.
32 FAO Deep-sea Guidelines, para 20.
33 FAO Deep-sea Guidelines, para 22.
34 Principle 15 of the Rio Declaration on Environment and Development, UNGA A/CONF.151/26 (Vol I), 12 Aug 1992.
35 UNFSA, Art 6.
36 NAFO Convention, 7th preambular para, and Article III (c).
37 See UNGA Resolutions 64/72 (2009), 66/68 (2011) and 71/123 (2016).
38 UNGA Resolution 71/123 (2016), para180.

(ii) Ensure that impact assessments, including cumulative impacts, are conducted in accordance with the FAO Guidelines[39] before authorising bottom fishing activities;

(iii) Ensure that conservation and management measures are based on updated best scientific information.

In the latest review, the UNGA resolution 71/123 encouraged RFMOs to map VMEs and to adopt measures to prevent SAIs, including the closure of areas to bottom fishing.[40]

It is important to note that the same resolution also noted with concern that VMEs may also be impacted by human activities other than bottom fishing and encouraged States and competent international organisations to consider taking action to address such impacts.[41] This is particularly relevant for the other anthropogenic pressures in the NRA (NAFO 2019)[42]. In this context, the CBD Revised Voluntary Guidelines for the Consideration of Biodiversity in Environmental Impact Assessments and Strategic Environmental Assessments in Marine and Coastal Areas (CBD EIA/SEA guidelines)[43] can be a useful instrument to be observed. The CBD EIA/SEA guidelines (which are applicable to areas within and beyond national jurisdiction) suggest that the following biodiversity questions be addressed in the EIA study:

(a) Would the proposed activity affect the biophysical environment directly or indirectly in a manner which poses risks to threatened, endangered or declining species or may cause changes to biological or ecological processes that may affect such species? Importantly, the guidelines recommend that the EIA terms of reference include the spatial and temporal scale of influence of each biophysical change, identifying effects on connectivity between ecosystems, and potential **cumulative effects.**[44] More specifically, the guidelines points to the need to consider cumulative threats and impacts from repeated impacts of projects of the same or different nature over space and time, as well as the cumulative effects of environmental changes such as climate change and ocean acidification.[45]

(b) Would the proposed activity surpass Minimum Sustainable Yield, the carrying capacity or a habitat/ecosystem, or cause significant adverse impacts as per the FAO deep-sea guidelines?

(c) Would the activity result in changes to access to and/or rights over biological resources?[46]

In addressing these questions, three levels of diversity in relation to conservation and sustainable use of biodiversity, are highlighted:

(a) Ecosystem diversity: Would the activity, directly or indirectly, lead to serious damage or total loss of (an) ecosystem(s) resulting in a loss of ecosystem services? In considering this question, the guidelines recommend considering whether the activity would cause substantial pollution or significant and harmful changes to an area described as an ecologically or biologically significant marine area (EBSA) as per criteria adopted by CBD decision IX/20.

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39 In particular para 47 of the FAO Guidelines.

40 UNGA Resolution 71/123 (2016), para 181.

41 UNGA Resolution 71/123 (2016), para 184.

42 NAFO. 2019. Report of the Scientific Council Working Group on Ecosystem Science and Assessment, 18 - 29 November 2019, Dartmouth, Nova Scotia, Canada. NAFO SCS Doc. 19/25.

43 CBD voluntary guidelines for the consideration of biodiversity in environmental impact assessments and strategic environmental assessments in marine and coastal areas CBD Decision XI/18 (2012).

44 Ibid, para 25 (d).

45 Ibid, para 31(f).

46 Ibid, para 28.

(b) Species diversity: Would the activity cause a direct or indirect loss of a population of a species, or affect the sustainable use of these?

(c) Genetic diversity: Would the activity result in extinction of a population of a localised endemic species, or cause a local loss of varieties of genes or genomes?[47]

With respect to the geographical areas important for biodiversity and ecosystem services that should receive special attention in the EIA screening phase and subsequent phases for mandatory EIAs, the guidelines make specific reference to VMEs, as well as EBSAs, marine protected areas (MPAs), IMO's Particularly Sensitive Sea Areas (PSSAs), International Seabed Authority's Areas of Particular Environmental Interest (APEI), sacred sites, areas traditionally used by indigenous peoples and local communities, breeding, nursery, feeding, spawning grounds or ecological corridors and migratory routes, and other important areas.[48]

In the context of the CBD, it is also important to highlight that the Aichi Biodiversity Targets adopted in 2010 are expiring in 2020 and will be replaced by new goals and targets under the Post-2020 Global Biodiversity Framework (GBF) to be adopted by the 15th Conference of the Parties (COP) currently scheduled to take place in 2021. The fifth edition of the Global Biodiversity Outlook (GBO-5) affirms with high confidence that Aichi Target 6[49] on sustainable fisheries has not been achieved, including in relation to the prevention of SAI on threatened species and vulnerable ecosystems.[50] GBO-5 also notes the relationship between Aichi Target 6 and the Sustainable Development Goals (SDGs) 14.2[51]and 14.4.[52] NAFO's scientific work on SAI can provide a model for the other regions in addressing this specific components of these global goals and targets.

Aichi Target 11 (protected areas and other effective area-based conservation measures - OECMs) was partially achieved according to GBO-5. The assessment notes that while progress has been made towards the achievement of the numeral target of 10% coverage for these spatial measures, the qualitative elements of the target (connectivity, effective and equitable management, ecological representativity and integration into the wider seascape) have not been sufficiently addressed. In this regard, it is important to note that in 2018 CBD COP adopted a definition[53] and criteria[54] for identification of OECMs, which could be particularly relevant for NAFO's measures on VMEs and its coordinating efforts with other sectoral organisations with a view to ensure that sustained and long-term biodiversity conservation outcomes are achieved. It is important to note that in accordance with the criteria, even though the governance of OECMs may be by a single authority/organisation, it is important that collaboration with relevant authorities in the given area takes place in order to provide the ability to address diverse threats collectively.[55] Furthermore, the CBD decision highlights the management should be consistent with the ecosystem approach to achieve long-term biodiversity conservation outcomes, including the ability to manage new threats.[56] Management should also be effective, in the sense that it should anticipate new threats and prevent, reduce or eliminate them, including through policy frameworks and

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47 Ibid, para 9.

48 Ibid, Appendix 1.

49 Aichi Target 6 reads: "B*y 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits*" (CBD Decision X/2 (2010).

50 CBD Secretariat, *Global Biodiversity Outlook 5* (GBO-5) (Montreal: CBDS, 2020).

51 "*By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans*" (SDG 14.2).

52 "*By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to the levels that can produce maximum sustainable yield as determined by their biological characteristics*." (SDG 14.4).

53 The adopted definition of OECMs is "*a geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in situ conservation of biodiversity, with associated ecosystem functions and services and where applicable, cultural, spiritual, socio-economic, and other locally relevant values*" (CBD decision 14/8 (2018), para 2).

54 See Annex III, Section B of CBD decision 14/8 (2018) for the Criteria for Identification.

55 CBD decision 14/8 (2018), Annex III, Section B, Criterion B.

56 CBD decision 14/8 (2018), Annex III, Section B, Criterion B.

regulations.[57] The work of WG-ESA on connectivity and ecosystem functions will also contribute to the potential recognition of OECMs in the NAFO NRA based on the criteria associated to information and monitoring that should document the known biodiversity attributes, the health of the ecosystems, and the need to have ecosystem functions and services supported by the respective measure.[58] Furthermore, the recognition of OECMs is expected to include the identification of the range of biodiversity attributes including areas providing critical ecosystem functions and services, and areas for ecological connectivity.[59]

The current draft text of the GBF includes OECMs in its spatial protection target, and will most likely still be included in the adopted text. FAO, the CBD Secretariat and the IUCN-FEG convened a workshop on fisheries-related OECMs in 2019[60] with a view to develop guidelines on the application of the CBD definition and criteria to fisheries in the future.

ii) Oceanographic Conditions

The NRA is influenced principally by two major ocean currents: the southward flowing Labrador Current to the east of the Newfoundland Shelf and Grand Banks and north of the Flemish Cap, and the North Atlantic Current which represents the bulk continuation of the warm Gulf Stream, flowing in an east-north easterly direction to the south and east of the Flemish Cap (Stein 2007).

The Labrador Current is a continuation of the Baffin Bay current, which carries cold and relatively low salinity waters of Arctic origin, with two main branches. The small inshore branch carries approximately 15% of the water transport and hugs the coast of Newfoundland and is unlikely to influence the Cap, whereas the offshore branch follows along the shelf-break. The offshore branch of the Labrador Current splits north of the Flemish Cap, with the main branch flowing through Flemish Pass, west of the Cap and along the eastern side of the Grand Banks, where it is reduced to a width of 50 km and a flow of 30 cm s-1 while the weaker side-branch flows in clockwise around the northern and eastern side of the Cap (Petrie and Anderson, 1983; Stein, 2007). Geostrophic calculations reveal that the body of the Labrador Current reaches a depth of 250-300 m in the Flemish Pass and that the side-branch reaches a depth of ~200 m (Maillet and Colbourne, 2007). According to Stein (2007), the lower end of temperature-salinity profiles of the Labrador Current in the Flemish Pass is achieved at a temperature of 3.3°C and a salinity of 34.8 at a depth of 800 m, while in the side-branch this is achieved a temperature of 3.5°C and a salinity of 34.8 at a depth of 610 m.

The North Atlantic Current is comprised of a combination of cold Slope Water Current and Warm Gulf Stream waters (Mann, 1967). Krauss *et al.* (1976) found that the North Atlantic Current generally looped around the northwest corner of the Flemish Cap after which it turns in an easterly direction, but in some circumstances meanders from the Current can result in significant easterly flow before it reaches the Flemish Cap. The lower end of the temperature-salinity profile is achieved at 1.69°C and salinity of 34.92 at a depth of 4 025 m (Stein, 2007).

Temperature profiles reveal that waters in areas west and north of the Flemish Cap are similar to conditions found in the Labrador Current and Labrador Sea, with relatively weak horizontal gradients. In contrast, conditions Flemish Pass and along the southern edge of the Grand Banks show strong horizontal gradients in temperature profiles, indicative of the contrast between the side-branch of the Labrador Current and the North Atlantic Current. The mean position of the frontal zone is relatively stable throughout the year (Stein, 2007). At the surface, the contrast between Labrador Current and North Atlantic Current waters may be of the order of ~10°C (Stein, 2007), while at depth waters surrounding the Cap on all sides are near 4°C. Waters associated with the Labrador Current have slightly higher concentrations of nitrate, silicate and oxygen than those associated with the North Atlantic Current (Maillet *et al.*, 2005).

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57 CBD decision 14/8 (2018), Annex III, Section B, Criterion C.

58 CBD decision 14/8 (2018), Annex III, Section B, Criterion C and D.

59 CBD decision 14/8 (2018), Annex III, Section B, Criterion C.

60 FAO. *Report of the Expert meeting on Other Effective Area-Based Conservation Measures in the marine capture fishery sector, Rome, Italy, 07-10 May 2019*. FAO Fisheries and Aquaculture Report No. 1301. (Rome: FAO, 2019).

iii) Ecosystems

The Flemish Cap ecosystem is isolated in relation to the near Grand Bank and Newfoundland shelf systems. The Flemish Pass, a channel with depth of c. 1 100 m, hinders the migration of the shallower benthic and demersal fish populations (but not deep water dwelling species) between the cap and the banks, while the quasi-permanent oceanic anti-cyclonic gyre (Colbourne and Foote, 2000) retains eggs and larvae over the cap that will eventually recruit to the Flemish Cap populations.

Primary production is high over the Flemish Cap (Berger *et al.*, 1989), which is related with the existence of a consistently elevated concentration of nutrients on the Flemish Cap, likely as a result of the influx of water from the North Atlantic current, through advection and mixing (Maillet, 2005). The high primary production supports secondary production in which copepods are the dominant zooplankton group. *Calanus finmarchicus* is the most important copepod species in terms of biomass, while small cyclopoid copepods of genus the *Oithona* and small calanoid copepods of the genus *Pseudocalanus* are of higher importance numerically. Other important groups in the zooplankton community are euphausiids, hyperiid amphipods, chaetognaths or ctenophores (Anderson, 1990). The zooplankton community represents a mixture of taxa from the Labrador Sea and the Newfoundland slope water, with a greater proportion of larger taxa than the adjacent continental shelf (Pepin *et al.*, 2011).

iv) Habitats

A habitat is an area where an organism or group of organisms live and breed. Habitats range in size, and their characteristics are determined by a large number of variables. As some organisms may move between habitats when looking for food or during different parts of their life cycle, definitions of marine habitats are often linked to the organism of interest (such as 'critical' habitats associated with listed or endangered species). Habitats in the pelagic realm are defined by light, currents and water mass characteristics and are temporally and spatially dynamic. Habitats in and on the sea floor are similarly defined by physical oceanographic properties with the addition of terrain variables detailing the geophysical landscape at various spatial scales, and biotic structural components. Benthic habitats defined by these additional attributes are more temporally and spatially stable than their pelagic counterparts. Circumscription of marine habitats may involve habitat suitability modeling (HSM) that links species occurrence, abundance and/or biomass to a suite of environmental predictor variables.

In the NRA (NRA), eleven benthic Vulnerable Marine Ecosystem (VME) Indicator species groups (Murillo *et al.*, 2011; NAFO, 2021) were identified under the FAO criterion for 'Structural Complexity' (FAO, 2009) and are an important subset of the benthic habitats in the region: Large-sized Sponge Grounds, Sea Pen Fields, Sea Squirt (*Boltenia ovifera*) Fields, Erect Bryozoan Turf, Tube-dwelling (Cerianthid) Anemone Fields, Sea Lily (crinoid) Fields, Black Coral Gardens, Large Gorgonian Coral Gardens, Small Gorgonian Coral Gardens, Stony Coral Reefs and Xenophyophore Aggregations (NAFO, 2021). These VMEs form spatially distinct biogenic habitats in the NRA (Kenchington *et al.*, 2019) which are linked to local enhancement of biodiversity (Kenchington *et al.*, 2020) and vulnerable to adverse impacts of bottom trawling gears. Kenchington *et al.* (2020) identified 95 taxa, including many non-VME species, from the EU Surveys of NAFO Divisions 3LMNO that they classed as 'habitat providers' based on a review of the scientific literature (their Appendix 17). These taxa were drawn from 6 phyla: Annelida, Bryozoa, Chordata, Cnidaria, Mollusca and Porifera, with the cnidarians being the most diverse (53 taxa) followed by the Porifera (30 taxa). Further, certain fish species such as the sand lance (*Ammodytes dubius*, Ammodytidae) burrow into the sand or gravel (Staudinger *et al.*, 2020) to a depth of ~ 8 cm (Nizinski *et al.*, 1990) and so have a requirement for specific geophysical habitats. Therefore the potential list of benthic habitats in the NRA is likely to be quite extensive.

For pelagic species, HSMs which include all or part of the NRA have been published for a variety of ecosystem components: *e.g.*, capelin (Andrews *et al.*, 2020), redfish, blackbelly rosefish, cod, Greenland halibut, roundnose grenadier and American plaice (Morato *et al.*, 2020), breeding seabird foraging areas (Huettmann and Diamond, 2001), and whales (Gomez *et al.*, 2017), while Fahay (2007) provides a qualitative description of the habitats of 760 species of fish from 196 families, including spawning habitats where known. WG-ESA is currently working on production of HSMs for the main target species in the NAFO managed fisheries (northern shrimp, Greenland halibut, American plaice, yellowtail flounder, witch flounder, thorny skate, redfish, Atlantic cod, capelin, white hake) (NAFO, 2020).

v) Communities

Fish

The Grand Banks, part of the Labrador Newfoundland Large Marine Ecosystem (LNLME), has historically been one of the world's richest fishing grounds. Dawe *et al.* (2012) show that a sharp ecosystem transition in dominant communities during the early 1990s, from finfish to crustaceans, was common to the 2 northernmost Northwest Atlantic ecosystems, the Newfoundland–Labrador shelf (NL) and the northern Gulf of St. Lawrence (nGSL). Fishery and survey data show that populations of Atlantic cod (*Gadus morhua)*, typical of most finfish species, collapsed during the late 1980s to early 1990s in both systems, while Greenland halibut (*Reinhardtius hippoglossoides)* populations changed little. Biomass of northern shrimp (*Pandalus borealis)* increased following the collapse of cod in both systems, likely due, at least in part, to release of predation pressure. Predation appeared to have relatively little effect on biomass of snow crab (*Chionoecetes opilio)*. Shrimp replaced capelin (*Mallotus villosus*) as the principal prey in the diet of cod and Greenland halibut in the mid-1990s. The contribution of shrimp to predator diets was generally highest when neither capelin nor other suitable prey (fish or squid) were available. Nogueira *et al.* (2015) examined the assemblage structure of the 24 most abundant fish species of the EU-Spanish surveys in the 3NO NAFO Regulatory Area (NRA) in the period 2002-2013. These 24 species (commercial and non-commercial) comprised 92.5% of the total trawl biomass. Of these taxa, 22 were demersal species. Of the remaining two, redfish is mesopelagic and capelin is pelagic. During 1988–2002, survey biomass indices indicated a shift in the predominant groundfish species from American plaice *(Hippoglossoides platessoides*) and Atlantic cod to yellowtail flounder *(Limanda ferruginea)* and redfish (*Sebastes mentella* and *Sebastes fasciatus*).

During the European Union fisheries surveys conducted in the Flemish Cap area yearly since 1988, 129 fish species were identified, 65 of them considered demersal based on FishBase information (www.fishbase.org). Since 1960, 99% of the average declared annual catches from Flemish Cap fisheries consist of demersal fish species, which is indicative of their dominance of the Flemish Cap fish assemblage. Unlike on the Newfoundland Shelf, pelagic species, such as capelin, herring (*Clupea harengus*) and sandlance (*Ammodytes dubius*) only occasionally appear on the Flemish Cap. Owing to the relatively high mean depth of the bank, the most important pelagic fishes found there belong to the order Myctophidae, especially *Myctophum punctatum*, *Ceratoscopelus maderensis* and *Benthosema glaciale* (Poletayev, 1980). In contrast, as shown by Alpoim *et al.* (2002), the most diverse fish orders in the Flemish Cap were the Rajiformes, Stomiiformes, Gadiformes, Osmeriformes, Perciformes and Scorpaeniformes, although from a fisheries perspective the most important species were Pleuronectiformes (American plaice and Greenland halibut), Gadiformes (cod and roughhead grenadier (*Macrourus berglax*)) and Scorpaeniformes (redfish species).

In the same survey, the most abundant demersal species were cod, redfish, Northern shrimp and Greenland halibut, all accounting, as an average, for 83.5% of total index of biomass every year. After the collapse of cod population in the early 1990s, the demersal community experienced very important variations (Pérez-Rodríguez *et al.*, 2012). Among the most important variations: (1) shrimp experienced a marked increase since 1993 and reached the highest levels ever observed in the late 1990s; (2) after 2003 the redfish stocks showed a rise in their biomass, which was followed by the decline of shrimp population; and (3) the decline of shrimp as well as redfish stocks became even more pronounced after the mid-2000s with the recovery of cod population, which, after various successful recruitment events since 2006, reached to the levels of biomass observed in the late 1980s. Water temperature, along with prey-predator interactions and fishing mortality were significant drivers for these changes (Pérez-Rodríguez *et al*., 2012).

Nogueira *et al.* (2017) analyzed the Flemish Cap survey data in the period of 2004–2013 and found that a total of 185 fish species were caught between 129 m and 1 460 m, with the 29 more important fish species comprising 99.2% and 99.1% of the catch in terms of biomass and numbers, respectively. Acadian redfish (*Sebastes fasciatus*) was the highest biomass (28.57% of the total fish species) and abundance (38.3% of the total fish species), while Greenland halibut (5.1% in biomass; 0.8% in abundance of total) and marlin-spike (*Nezumia bairdii*) (0.3% of total in biomass and abundance) were the most frequently caught taxa (highest 71% occurrence).

Epibenthos

Epibenthos are organisms that live on the surface of the seafloor. They provide important roles in the marine environment. Through their physical structure, some epibenthic organisms enhance habitat complexity increasing biodiversity and ecosystem function (*e.g.*, Danovaro *et al.*, 2008; Buhl-Mortensen *et al.*, 2010), provide nursery areas (*e.g.*, Aldrich and Lu, 1968; Etnoyer and Warrenchuk, 2007) and modify biochemical regimes (*e.g.*, Kaufmann and Smith, 1997; Gallucci *et al.*, 2008). These structural habitats can also contribute to vertical relief, modify water quality and flow, and increase the availability of microhabitats in areas that often have little three-dimensional relief (*e.g.*, Tissot *et al.*, 2006; Baillon *et al.*, 2014). Additionally, they represent a key link between benthic and pelagic ecosystems (*e.g.*, Piepenburg *et al.*, 1997; Griffiths *et al.*, 2017), facilitating nutrient cycling (*e.g.*, Perea-Blázquez *et al.*, 2012; Maldonado, *et al.*, 2020) and some are an important food source for fish and marine mammals (*e.g.*, Oliver *et al.*, 1983; Bowen, 1997; González *et al.*, 2006). Due to their low mobility and longevity, some epibenthic organisms are good indicators of the effects of fishing, oil spills, and climate change (*e.g.*, Kaiser *et al.*, 2000; White *et al.*, 2012; Kortsch *et al.*, 2012), and therefore can provide a 'measurable' level of impact. Epibenthos can be sampled using different equipment and techniques such as epibenthic sleds, dredges, trawls, or remotely operated vehicles amongst others (Eleftheriou and McIntyre, 2005).

Several studies targeting particular epifaunal groups, such as corals, sponges, nudibranchs, etc., have been undertaken by different authors in the NRA (*e.g.,* Wareham, 2009; Murillo *et al.*, 2012; Valdes *et al.*, 2016). Whereas, descriptions of the epibenthic communities have been provided by Nesis (1962, 1965) and Murillo *et al.* (2016) for the Grand Bank and Flemish Cap area, and Lapointe *et al.* (2020) for the New England and Corner Rise Seamounts. Murillo *et al.* (2016) identified 439 epibenthic invertebrates from 287 depth-stratified random trawls carried out in the Tail of the Grand Bank and Flemish Cap between 45 and 1500 m depth. Using a subset of 152 uniquely identified taxa, they identified twelve spatially coherent epibenthic megafaunal assemblages, nested within three major regional-scale faunal groups: (1) the continental shelf of the Tail of the Grand Bank; (2) the upper slope of the Grand Bank and top of Flemish Cap; and (3) the lower slope of the Grand Bank and Flemish Cap. These major faunal group appear to have persisted at least since the middle of the last century when they were originally described by Nesis (1962, 1965). Two of the assemblages from the lower slopes of the Grand Bank and Flemish Cap were dominated by deep-sea corals and sponges and associated with high ecological and functional diversity and important ecosystem functions such as bioturbation, nutrient cycling and habitat provision (section 7.b)i); Kenchington *et al.*, 2020; Murillo *et al.*, 2020a, 2020b. Beazley *et al.* (2013, 2015) provided additional information on the diversity associated with sponge grounds of the Sackville Spur area and in Flemish Pass based on *in situ* imagery. Other VME Indicator taxa, such as the large sea squirt *Boltenia ovifera* and the erect bryozoan *Eucratea loricata* were significantly associated with the communities from the Tail of the Grand Bank at 57-320 m and 46-86 m depth, respectively (Murillo *et al.*, 2016). From these studies it is known that the epibenthic communities are aligned with bottom depth and oceanographic features, similarly to the fish assemblages described from the area (*e.g.,* Paz and Casas,1992; González-Troncoso *et al.*, 2006; Nogueira *et al.*, 2013). Additionally, areas of highly intensive fishing activity, such as Sackville Spur, Flemish Pass and south of Flemish Cap were associated with lower epibenthic diversity (Murillo *et al.*, 2020a, 2020b) and presented epibenthic assemblages with the least spatial cohesion (Murillo *et al.*, 2016).

Infauna

Infauna are benthic animals that live in sea floor sediments. Most benthic infauna construct burrows that connect to the sediment–water interface to facilitate respiration, feeding, and other metabolic processes, and as a consequence play a key role in biogeochemical cycling and nutrient fluxes in marine ecosystems (see Kenchington *et al.*, 2020 for ecosystem functions of bioturbators). Infauna are especially effective for the study of spatial and temporal effects of environmental change as a result of their low mobility and relative longevity (Gray and Elliot, 2009), and are sampled using benthic grabs or corers which collect intact sections of the sea bed. Infauna categories are defined in terms of their size, as determined from their retention through a series of sieves: microfauna (< 0.1 mm), meiofauna (< 1 mm), macrofauna (> 0.5 mm), and megafauna (> 10 mm). Meiofauna (*e.g.*, nematodes and foraminiferans) are concentrated in the uppermost 2 cm sediment layer while macrofauna (*e.g.*, polychaetes, Arthropoda) are most abundant in the top 10 cm (Montagna *et al.*, 2017). Grab samples typically include both infauna and epifauna (Section 7.a).v) and researchers generally report their work using the size classifications, irrespective of location of the taxa in the sediment. Consequently information specific to infaunal communities often has to be inferred from the literature based on species lists and knowledge of the life history characteristics. Further, mechanical grabs such as Van Veens are often small in size which limits the depth of penetration which restults in an under-representation of some of the large and deeper-living species in the samples, such as the clam *Cyrtodaria siliqua* (Gilkinson, 2013).

Table 7.1. Synopsis of research conducted in the NRA with a focus on grab-sampled infauna. * It is not clear how many of these stations are in the NRA. The numbers reported are for the full study which included the continental shelves in Canadian waters.

NAFO Division(s) (NRA)	Sampling Gear	Size Fraction	Number of Samples (Stations)	Depth Range (m)	Research Programme	Reference(s)
3LMNO	Weighted 0.25 m2 bottom scoop "Ocean-50"	Macrofauna; megafauna	163 (163)*	45 -1500	-	Nesis (1965; translation 1970)
3L	0.1 m2 Van Veen grab	Macrofauna	(1)	44-51	Environmental Impact Assessment	Hutcheson *et al.* (1981)
3N	0.053-m2 Ponar grab	Macrofauna	40 (15)	76 -1129	-	Houston and Haedrich (1984)
3N	0.1 m2 Van Veen grab	Macrofauna; megafauna	(11)	58? -157	NEREUS	Gilkinson (2013)
3LMNO	0.25 m2 ULSNER Mega Box Corer	Macrofauna; megafauna	312 (312)	582 - 2294	NEREIDA	Barrio Froján *et al.* (2012, 2016); Ashford *et al.* (2018, 2019a, b)

Studies which include grab-sampled infauna from the NRA are summarized in Table 7.1. None of these studies separately identified infauna from epifauna but it is clear that the region has a diverse infaunal community influenced by sediment type and numerically dominated in some areas by polychaetes and sipunculans (Houston and Haedrich, 1984), with a number of clam species dominating biomass. In particular, an extremely large biomass of Turton's wedge clam (*Mesodesma deauratum*) has persisted on the Southeast Shoal (Hutcheson and Stewart, 1994; Gilkinson, 2013). These clams may be glacial relicts of shallow littoral populations living in the area during the late Wisconsinan period, as they are typically found in shallow littoral habitats (< 12 m) (Hutcheson and Stewart, 1994). The dominant infaunal taxa recorded in the NRA are consistent with other regions where Polychaeta, Mollusca, and Crustacea dominate the infauna (*e.g.*, Kenchington *et al.*, 2001; Schonberg *et al.*, 2014; Montagna *et al.*, 2017). Kenchington *et al.* (2001) analyzing 200 grab samples from an experimental site on Grand Bank inside the Canadian EEZ, and found 246 taxa, primarily polychaetes, crustaceans, echinoderms, and molluscs. Biomass was dominated by propeller clams (*Cyrtodaria siliqua*) and the sand dollars (*Echinarachnius parma*) which are epifaunal but bury in the top layers of the sediments, while abundance was dominated by the polychaete *Prionospio steenstrupi* and the mollusc *Macoma calcarea*. Depth, sediment temperature, and the proportion of clay within sediments are important in shaping the grab-sampled faunal assemblages (Barrio Froján *et al.*, 2012).

Despite their position in the sediment, the scientific evidence indicates that infauna are susceptible to adverse impacts caused by bottom-contact fishing gears (*e.g.*, Kenchington *et al.*, 2001; Jennings *et al.*, 2002; Hinz *et al.*, 2009; Ragnarsson and Lindegarth, 2009; Mangano *et al.*, 2014). For example, Hinz *et al.* (2009) found that chronic commercial otter trawling for *Nephrops* on muddy bottoms in the northeastern Irish Sea had a significant, negative effect on infaunal abundance, biomass, and species richness. However, other studies have not been able to detect a significant impact of otter trawling on infauna (*e.g.*, Drabsch *et al.*, 2001) or else recorded a delayed response (Sanchez *et al.*, 2000). Gilkinson *et al.* (1998) document the displacement and damage to bivalves caused by interaction with otter trawl doors in a laboratory test tank using sandy sediments. The impacts of the doors are likely to be greater than those of the net, but are often difficult to distinguish between in the field due to the ability to collect samples with precision using most sampling tools.

vi) Description of ecosystem production units

Ecosystems are not homogenous; they are organized in a hierarchical way, where different physical and biological processes operate at different spatial scales. It is the integration of these processes in space and time what defines a functional system, where trophic interactions are main mechanism for transfer of energy among the different biological populations. From this functional perspective, three spatial scales have been identified as relevant for the development of ecosystem summaries and ecosystem-level management plans: Bioregion, Ecosystem Production Units (EPUs), and Ecoregion. The EPU is the spatial scale considered more appropriate for integrated fisheries management plans because it defines a major geographical subunit within a Bioregion characterized by distinct productivity and a reasonably well defined major marine community/food web system.

Current analyses in the NAFO Convention Area have been focused on continental shelves ecosystems from the northern Labrador to the Mid-Atlantic Bight and have allowed identifying four major Bioregions (Newfoundland and Labrador Shelves, Flemish Cap, Scotian Shelf and Northeast US Continental Shelf) (NAFO 2014, 2015, Pepin *et al.*, 2014). From these bioregions, only two extend into the NRA. The Flemish Cap Bioregion is entirely within the NRA, and the Newfoundland and Labrador Shelves Bioregion extend beyond Canada's EEZ into the NRA in the areas known as the Nose and Tail of the Grand Bank.

In terms of EPUs, the Flemish Cap Bioregion contains a single EPU (*i.e.*, bioregion and EPU are the same, the shelf area within NAFO Div. 3M), while three EPUs have been identified in the Newfoundland and Labrador Shelves Bioregion: the Labrador Shelf EPU (shelf area within NAFO Divs 2GH), the Newfoundland Shelf EPU (shelf area within NAFO Divs 2J3K), and the Grand Bank EPU (shelf area within NAFO Divs 3LNO) (NAFO 2014, 2015, Pepin *et al.*, 2014). Based on preliminary analyses, a fourth EPU in this bioregion can be associated with the shelf area in NAFO Subdiv. 3Ps. On this basis, only two continental shelf EPUs are in the NRA, the Flemish Cap and the Grand Bank. The first one is entirely within the NAFO fishing footprint, while only the Nose and Tail from the Grand Bank EPU are part of the NAFO footprint.

Comparative analysis of the productivity of these two EPUs and overall fishing levels indicate that these ecosystem units have been overfished in the past, with more severe overfishing levels in the Grand Bank EPU (Koen-Alonso *et al.*, 2013, NAFO 2014). These EPUs experienced major changes in their fish communities during the last decades (NAFO 2010, Koen-Alonso *et al.*, 2010, Pérez-Rodriguez 2012, Nogueira *et al.*, 2017). In the case of the Grand Bank EPU, these changes are associated to a regime shift that has been formally recognized for the Newfoundland and Labrador Shelves Bioregion during the 1990s (Buren *et al.*, 2014). As a consequence of these changes, it is believed that the fisheries productivity of the Grand Bank EPU remains impaired until this day (NAFO 2014, 2015, 2019).

Unlike most NL EPUs, the Flemish Cap (3M) did not show a decline in total biomass during the groundfish collapse, and actually experienced a temporary increase in total biomass during the mid-late 2000s associated to buildups of plankpiscivores (redfish). While the current structure of the Flemish Cap community shows a declining dominance of piscivores (*e.g.,* cod), plankpiscivores appear to be increasing in relative dominance, while large benthivores remain at comparatively lower levels relative to their abundance in the late 1980s-early 1990s (NAFO 2018).

Taking into account current catches and productivity level, both EPUs can be considered fully exploited at the present time. The Flemish Cap productivity does not appear impaired, so this EPU is being exploited at its maximum potential. The current Grand Bank EPU fisheries productivity is estimated to be around 40% of its maximum potential, suggesting that rebuilding the functionality of this EPU could allow more than doubling of current catch levels (NAFO 2014, 2015, 2019).

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VMEs

i) Defining, identifying & mapping VMEs

Marine biogenic habitats (Section 7.a)iv), such as cold-water coral gardens and sponge grounds are created by living organisms that form three-dimensional structures that create niches for other species and thereby locally enhance biodiversity. The United Nations General Assembly resolutions calling for the protection of Vulnerable Marine Ecosystems (VMEs) highlight the biodiversity that such areas contain (Section 7.a)i). For a VME indicator to qualify as a VME, it should be present in significant concentrations (habitat forming), or in the case of uniqueness or rarity, be associated with an area or ecosystem whose loss could not be compensated for by similar areas or ecosystems elsewhere (FAO, 2009). Identification of what species/habitats qualify as VME indicators is based on five criteria established by FAO in 2009:

1. Uniqueness or rarity;
2. Functional significance of the habitat;
3. Fragility;
4. Life history traits of the component species that make recovery difficult;
5. Structural complexity.

Murillo *et al.*, (2011) reviewed over 500 taxa known to occur in the NAFO Regulatory Area (NRA) against the FAO criteria for a VME Indicator. The 88 VME indicator species thus far identified as occurring in the NRA, including the seamounts (NAFO, 2021), were mostly identified on the basis of 5th criterion, structural complexity, although many also possessed one or more of the other traits. Large-sized sponges, sea pens, small and large gorgonian corals, erect bryozoans, sea squirts (*Boltenia ovifera*), tube-dwelling (cerianthid) anemones, sea lilies (crinoids), stony corals, black corals and xenophyophores all meet the criteria for VME indicators and are known to produce dense aggregations.

NAFO undertook a review of the areas closed to protect VMEs in 2013/2014 (NAFO, 2013). They created operational definitions (NAFO, 2013) for VME indicators, VME elements, higher concentration observations of VME indicator species (*i.e.*, “significant concentrations”) and VMEs (see Text Box). To quantitatively identify significant concentrations of VME indicator taxa in the NRA, kernel density estimation (KDE) was applied to research vessel trawl survey data. In response to a request from the NAFO Commission and following the procedures applied in 2013, these analyses were updated in 2019 using all available data from the Canadian and EU-Spanish trawl survey data in support of the current review of the closed areas (NAFO, 2020).

KDE utilizes spatially explicit data to model the distribution of a variable of interest. It is a simple non-parametric neighbour-based smoothing function that relies on few assumptions about the structure of the observed data and uses minimal interpolation. It has been used in ecology to identify hotspots, that is, areas of relatively high biomass/abundance. With respect to marine benthic invertebrate species, it was first applied to the identification of significant concentrations of sponges in the NRA in 2009 (Kenchington *et al.*, 2009) followed by an application to sea pens (Murillo *et al.*, 2010). Since then it has been used to identify significant concentrations (VMEs) of corals, sponges and other VME indicators from research vessel trawl survey catch data in both Canada (Kenchington *et al.*, 2016) and in the NRA (NAFO, 2013; Kenchington *et al.*, 2014). These KDE polygons, run separately for each VME indicator group (NAFO, 2021) equate to the VME (see Text Box).

> **Vulnerable Marine Ecosystem (VME) (NAFO, 2013)**. Under the structure-forming criterion, it is a regional habitat that contains VME indicator species at or above significant concentration levels. These habitats are structurally complex, characterized by higher diversities and/or different benthic communities, and provide a platform for ecosystem functions/processes closely linked to these characteristics. The spatial scale of these habitats is larger than the footprint of a higher concentration observation. NAFO has used quantitative methods to objectively define areas that contain VME indicator species at or above significant concentration levels. These areas are not simply defined by the individual tows above the threshold value but also all of the smaller catches within the delimited polygon. These smaller catches may represent recruitment or smaller species in the VME indicator group. These larger areas are the VMEs proper unless post-hoc considerations suggest otherwise. VMEs occur throughout the NRA and their spatial arrangement may be important to recruitment processes and to overall ecosystem

KDE analyses does not incorporate environmental data into the analyses and in some instances, for example where a polygon crosses from the slope to the shelf, additional information can be used to improve the precision of the VME polygons (see Text Box). Species distribution models (SDMs) have been used to complement the KDE to further evaluated the configuration of the VMEs and to identify areas where VMEs are 'likely to occur' (UNGA Resolution 61/105). SDMs, or habitat suitability models as they are sometimes known (Section 7.a)iv), predict the presence, absence or abundance/biomass of a species or habitat (the response variable) from environmental variables thought to influence it (the predictor variables). SDM for sponge grounds (Knudby *et al.*, 2013 a,b), black corals, large gorgonian corals and sea pen corals (Knudby *et al.*, 2013c), the glass sponge *Asconema foliatum* (NAFO, 2020), erect bryozoans and sea squirts (*Boltenia ovifera*) (Kenchington *et al.*, 2019) are incorporated into the NAFO assessment of VMEs. These models are particularly valuable in areas where the survey vessels do not sample (*e.g.*, rough bottom, cliffs, depths greater than 1500 m) and for non-aggregating taxa that are present in low frequency and their past occurrence (noted after removal by the trawl) may or may not reflect the presences of other colonies in the same area. They can also be used to evaluate the area between trawl sets to determine if the full KDE polygon is potential habitat. With the exception of the SDM for *Asconema foliatum* (NAFO, 2020), erect bryozoans and sea squirts, the SDMs used for the 2013 assessment (NAFO, 2013; NAFO, 2018) were used in the 2019 re-assessment. New SDMs (Kenchington *et al.*, 2019) for the erect bryozoans and the sea squirts were undertaken building on previous requests (NAFO, 2017) to refine the distributions of those taxa.

For two VME indicator groups (Tube-dwelling anemones (cerianthids) and Sea lilies (crinoids)), updated distribution maps were provided, drawing on up-to-date data from the RV trawl surveys, NEREIDA rock dredge samples and NEREIDA underwater imagery (NAFO, 2020).

The analyses used to identify VMEs for each VME indicator group in the 2019 re-assessment (NAFO, 2020) were:

1. Large-sized Sponges: kernel analyses, SDM
2. Large gorgonian corals: kernel analyses, SDM
3. Small gorgonian corals: kernel analyses
4. Sea pens: kernel analyses, SDM
5. Erect bryozoans: kernel analyses, SDM (new)
6. Sea squirts: kernel analyses, SDM (new)
7. Tube-dwelling (Cerianthid) anemones: distribution
8. Sea lilies (Crinoids): distribution
9. Black coral: kernel analyses, SDM.

The congruence between the KDE-generated VME polygons and areas of predicted occurrence derived from SDMs were examined, where available, and used to modify the polygons (NAFO, 2020) to eliminate areas where the taxon was not predicted to occur (as was done previously; NAFO, 2015).

ii) VME polygon boundaries

The location of the VME polygons for large-sized sponges, sea pens, small and large gorgonian corals, erect bryozoans, sea squirts (*Boltenia ovifera*), and black corals are shown in Figure 7.1 in relation to the 2017 areas closed to protect corals and sponges and the NAFO fishing footprint. The 2017 closed areas are shown as one of these, Area 14, was opened to fishing in 2019 (NAFO, 2021); an action which is currently being reviewed. These VMEs were identified following the quantitative analyses outlined in Section 7.b)i.

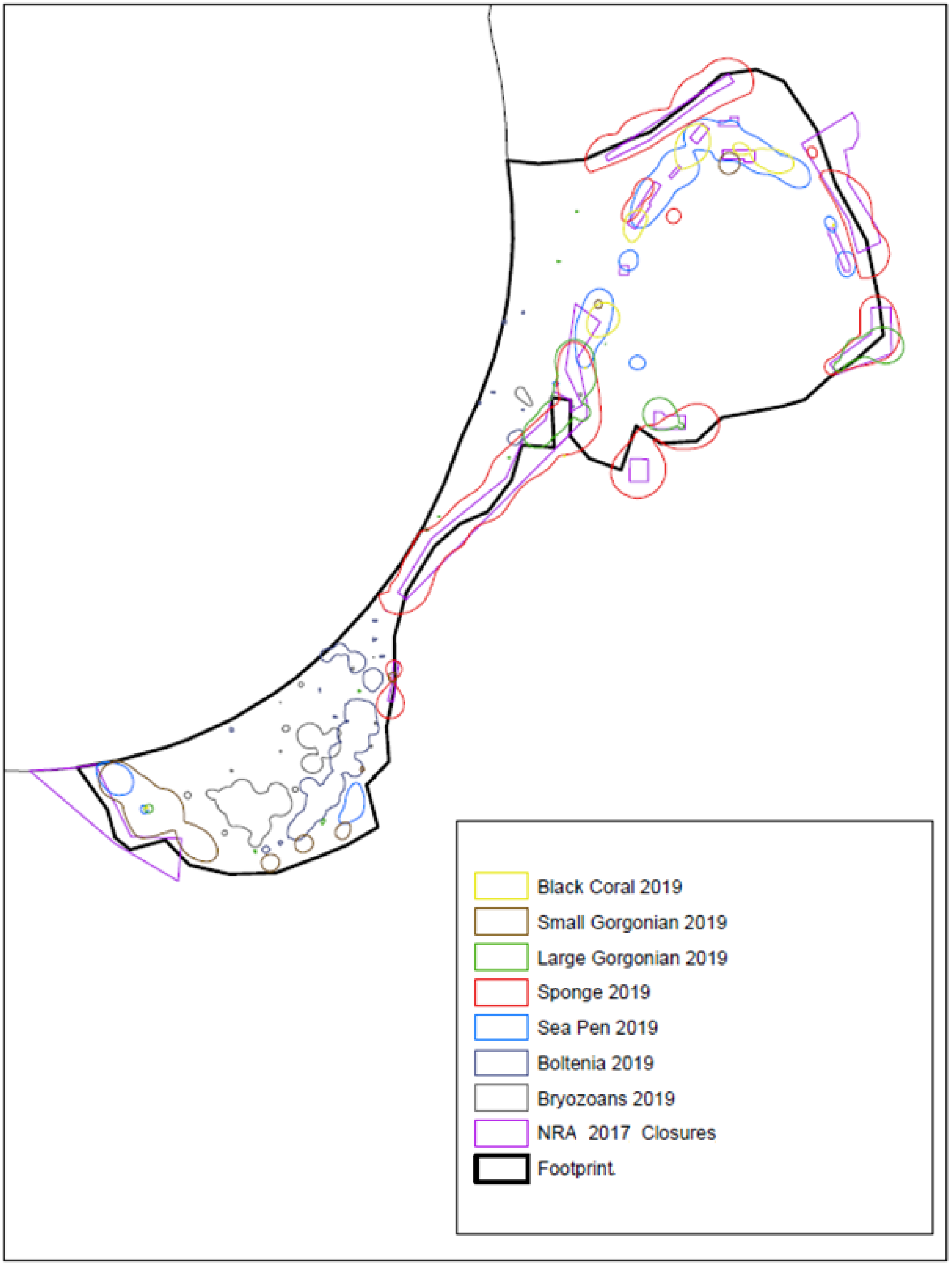

Figure 7.1. The location of the VME polygons for large-sized sponges, sea pens, small and large gorgonian corals, erect bryozoans, sea squirts (*Boltenia ovifera*), and black corals in relation to the 2017 areas closed to protect corals and sponges and the NAFO fishing footprint.

iii) VME biomass (grids)

In support of the NAFO review of the closed areas to protect Vulnerable Marine Ecosystems (VMEs) in the NRA, biomass estimates of Large-sized Sponges, Sea Pens, Sea Squirts (*Boltenia ovifera*), Erect Bryozoans, Black Corals, Large Gorgonian Corals, and Small Gorgonian Corals were undertaken, ultimately to evaluate the effectiveness of the closures in protecting VMEs. Biomass surfaces for the VME indicators are also required in order to evaluate impacts of fishing (significant adverse impacts; SAI). Previously, area occupied by the VME polygons and associated biomass were calculated for each VME indicator type using the output kernel density raster surfaces, which measure biomass as kg per unit area (in this case, per km^2) for each raster cell across the data range, and is therefore more accurately referred to as a biomass density rather than a true biomass (NAFO, 2020). The decision to use the KDE biomass surfaces to represent VME indicator biomass was made knowing that it was not the most accurate way to estimate true biomass. However, KDE surfaces were available for seven of the nine VME indicator taxa and so allowed for the effectiveness of the closed areas to be initially examined (NAFO, 2020). Here, we have calculated true biomass estimates from research vessel catch data for each of the 7 VME Indicator taxa following the general procedures established previously in Cogswell *et al.* (2011) with improvements and modifications as detailed in Lirette *et al.* (2020).

Summary of Data Sources

Available data for each VME indicator type were obtained from research vessel trawl surveys conducted between 1995 and 2019 (Table 7.2). These are the same data used to calculate the updated kernel density polygons (Kenchington *et al.*, 2019) used to delineate the location of VMEs for the review of areas closed for their protection (NAFO, 2020).

Table 7.2. Data sources from contracting party research vessel surveys; EU, European Union; DFO, Department of Fisheries and Oceans; NL, Newfoundland and Labrador; IEO, Instituto Español de Oceanografia; IIM, Instituto de Investigaciones Marinas; IPMA, Instituto Português do Mar e da Atmosfera.

Programme	Period	NAFO Division	Gear	Mesh Size in Codend Liner (mm)	Trawl Duration (min)	Average Wingspread (m)
Spanish 3NO Survey (IEO)	2002 - 2019	3NO	Campelen 1800	20	30	24.2 – 31.9
EU Flemish Cap Survey (IEO, IIM, IPIMAR)	2003 - 2019	3M	Lofoten	35	30	13.89
Spanish 3L Survey (IEO)	2003 - 2019	3L	Campelen 1800	20	30	24.2 – 31.9
DFO NL Multi-species Surveys (DFO)	1995 - 2019	3LNO	Campelen 1800	12.7	15	15 - 20

Spatial Extent of the Analyses

In order to satisfy the dual requirements of providing a biomass surface for evaluating significant adverse impacts of fishing and for determining the degree of protection afforded the VME indicators under different scenarios, the spatial extent shown in Figure 7.2 was used. This extent covers the NAFO NRA inside the fishing footprint, as well as significant concentrations of VME indicators, *i.e.*, VMEs (VME polygons: KDE polygons modified in some cases using species distribution models), and areas closed for their protection, outside of the fishing footprint. Area 14 was re-opened to fishing in January 2019 (NAFO, 2020), but is included in this assessment as part of an evaluation of that decision.

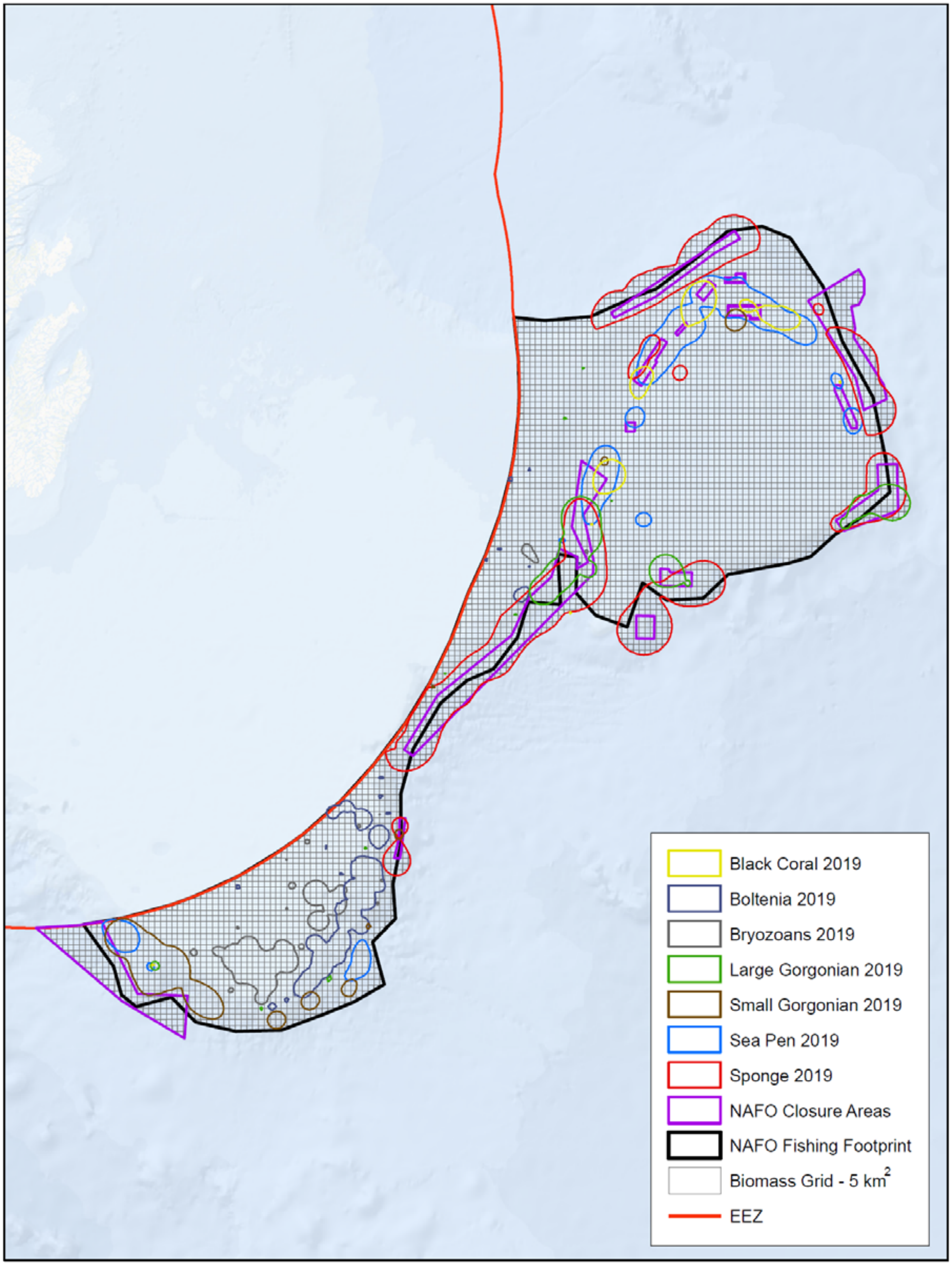

Figure 7.2. The spatial extent and 5 km x 5 km grid cell overlay used to estimate the biomass of VME indicators in relation to the fishing footprint (heavy black line), areas closed to protect VME (purple outline), and the location of the VMEs (VME polygons) for seven VME indicators (from Kenchington *et al.*, 2019). Projection: NAD 1983 UTM Zone 23N projection coordinate system.

The spatial extent (Figure 7.2) was partitioned into 5,701 grid cells, each 5 km x 5 km in size. Mean biomass per RV trawl was calculated from the RV catch data for each VME Indicator within each grid cell and total biomass was estimated using the swept area of the trawl gear and upscaling to the cell area of 25 km^2. All biomass calculations were done in ArcMap version 10.7 with layers projected using the NAD 1983 UTM Zone 23N projection coordinate system. Cells with no RV data were populated using focal statistics in ArcMap version 10.7, with a 3 x 3 cell neighbourhood. Focal statistics were applied iteratively with the same neighbourhood size until all 5,701 grid cells were populated. Full details are provided in Lirette *et al.* (2020). For the evaluation of significant adverse impacts of fishing, the VME biomass inside the VME polygons is required at a 1 km x 1 km resolution to match the reporting of fishing activity through VMS. As explained in Lirette *et al.* (2020) the most robust way of achieving this, given the spatial distribution of the RV data relative to the grid cell size was by overlaying the 1 km x 1 km grid onto the 5 km x 5 km grid such that the total biomass in each 1 km^2 grid cell will be $1/25^{th}$ of the total in the 25 km^2 grid cell. This reduced reliance on focal statistics to populate empty grid cells, and improved estimates of mean biomass per RV trawl per grid cell. For both grid mesh sizes shapefiles of the estimated biomass for each VME Indicator separately and for the total VME biomass were produced. This process was automated using ModelBuilder and documented in Appendices of Lirette *et al.* (2020) to increase transparency and reproducibility. The resultant biomass surfaces are illustrated in Figure 2. The gridded biomass data was made available to WG-ESA in GIS format to further the work on SAI.

Summary of the Partitioning of VME Indicator Biomass Inside the VMEs and Inside the Closed Areas

To facilitate examination of the effectiveness of the closed areas in protecting VMEs we partitioned the VME Indicator biomass into the total biomass found in the spatial extent (Figure 7.2), the biomass found within the KDE polygons described by Kenchington *et al.* (2019) as raw values and a percent of the total biomass, and the biomass found within the closed areas, also as raw values and the percent of the total biomass. This was done for both the 5 km and 1 km grids (Table 7.3) due to the small differences created in downscaling (see Lirette *et al.*, 2020).

Total Biomass of All VME Indicators Combined

To calculate total VME biomass, the individual VME Indicator biomass 5 km grids (Figure 7.3) were overlain on one another. To get a total VME wet weight biomass for the spatial extent we summed the biomass of all VME Indicators in each grid cell (Figure 7.3, Table 7.3). To get a spatial overview of the number of VME Indicators occurring we mapped VME Indictor Diversity. For each grid cell the number of non-zero biomass layers was calculated to get the number of VME Indicators present (VME Indicator Diversity; Figure 7.3). In many grid cells there are more than one VME Indicator taxon present (Figure 7.3). The eastern Flemish Cap shows the greatest overlap with some cells having up to six (6) of the seven (7) VME Indicators present.

Biomass Inside VME Polygons

As the VME polygon and closed area boundaries did not follow the perimeter of the grid cells, methodology to clip the biomass and estimate the portion inside the areas was implemented (Lirette *et al.*, 2020). An example is shown in Figure 7.3 for the total VME biomass and VME Indicator Diversity inside all VME polygons. Additionally, the biomass of each VME indicator were summated to give a total VME biomass for each grid cell, as a number of grid cells contained more than one VME Indicator in their catches (Figure 7.3, Table 7.3).

The large-size sponges have the highest VME biomass in the spatial extent, and the largest proportion of that biomass encapsulated in the VME polygons and in the area closures. The large gorgonian corals have a large proportion of their biomass protected as well, however the other VME Indicators have low protection from the closed areas (Table 7.3). This is particularly true for sea pens that have a high total regional biomass of which only 25% is found in the closed areas. This includes Area 14 which is currently open to fishing; therefore the actual percentage of sea pen biomass under closed area protection would be even smaller. For most groups the VME polygons (Kenchington *et al.*, 2019) capture a large proportion of their estimated biomass, the exception being the small gorgonian corals of which only 24% of the estimated total biomass in the region is within the VME polygons.

Table 7.3. Biomass estimates for each of 7 VME Indicators for the full spatial extend (Figure 7.2), the portion inside the VME polygons for the VME Indicator (Kenchington *et al.*, 2019) and the portion inside the closed areas. Estimates made separately using the 5 km x 5 km and 1 km x 1 km grids.

VME Indicator	**5 km Grid (Total Biomass in Kg)**	**5 km Grid (Kg Biomass Inside VME)**	**% Biomass (Inside VME)**	**5 km Grid (Kg Biomass Inside Closed Area)**	**% Biomass (Inside Closed Areas)**
Large-size Sponge	293,432,034.0	277,136,159.1	94.4	226,209,845.6	77.1
Sea Pens	170,906.8	88,682.1	51.9	42,744.5	25.0
Sea Squirts	48,761.3	41,558.8	85.2	290.0	0.6
Erect Bryozoans	72,069.3	65,545.6	90.9	541.4	0.8
Black Coral	21,074.5	9,609.7	45.6	3,303.7	15.7
Large Gorgonian Corals	150,723.5	124,004.1	82.3	96,311.0	63.9
Small Gorgonian Corals	13,850.3	3,325.3	24.0	3,042.9	22.0
Sum of VME Biomass	**293,909,419.7**	**277,468,884.7**	**94.4**	**226,356,079.2**	**77.0**
VME Indicator	**1 km Grid (Total Biomass in Kg)**	**1 km Grid (Kg Biomass Inside VME)**	**% Biomass (Inside VME)**	**1 km Grid (Kg Biomass Inside Closed Areas)**	**% Biomass (Inside Closed Areas)**
Large-size Sponge	293,222,474.5	277,886,809.0	94.8	225,750,338.4	77.0
Sea Pens	170,691.0	88,682.1	52.0	42,744.2	25.0
Sea Squirts	48,761.3	41,558.8	85.2	290.0	0.6
Erect Bryozoans	72,069.0	65,545.6	90.9	541.4	0.8
Black Coral	20,887.9	9,609.7	46.0	3,303.4	15.8
Large Gorgonian Corals	149,440.6	124,004.1	83.0	96,311.0	64.4
Small Gorgonian Corals	13,845.5	3,325.3	24.0	3,042.2	22.0
Sum of VME Biomass	**293,698,169.8**	**278,219,534.6**	**94.7**	**225,896,570.7**	**76.9**

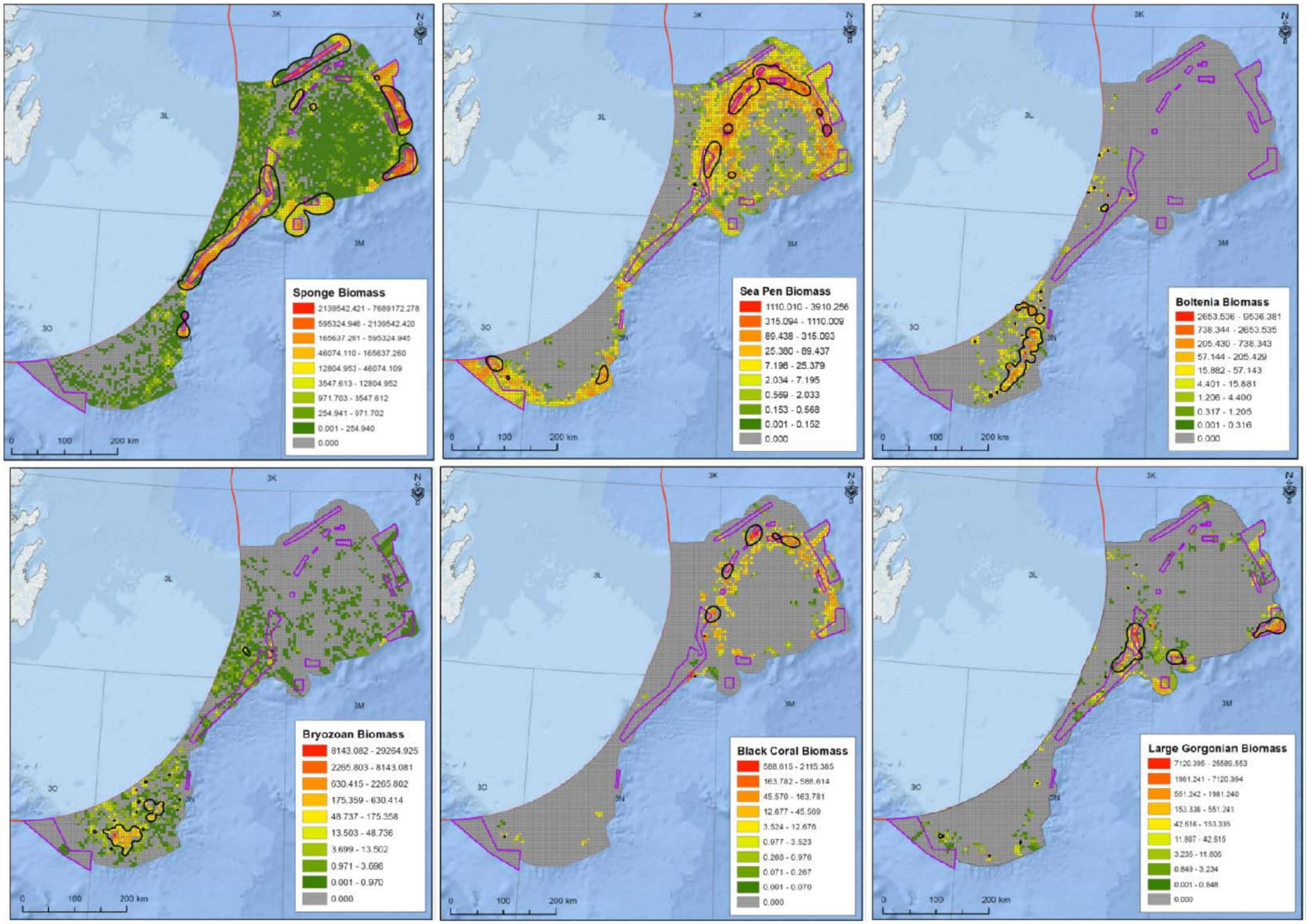

Figure 7.3. Gridded wet weight biomass (kg/25 km^2) for the VME Indicator taxa. Upper left to right: Large-size sponges, sea pens and sea squirts. Lower left to right: Erect bryozoans, black corals and large gorgonian corals. VME polygons for each indicator taxon are outlined in black. Closed areas are outlined in purple.

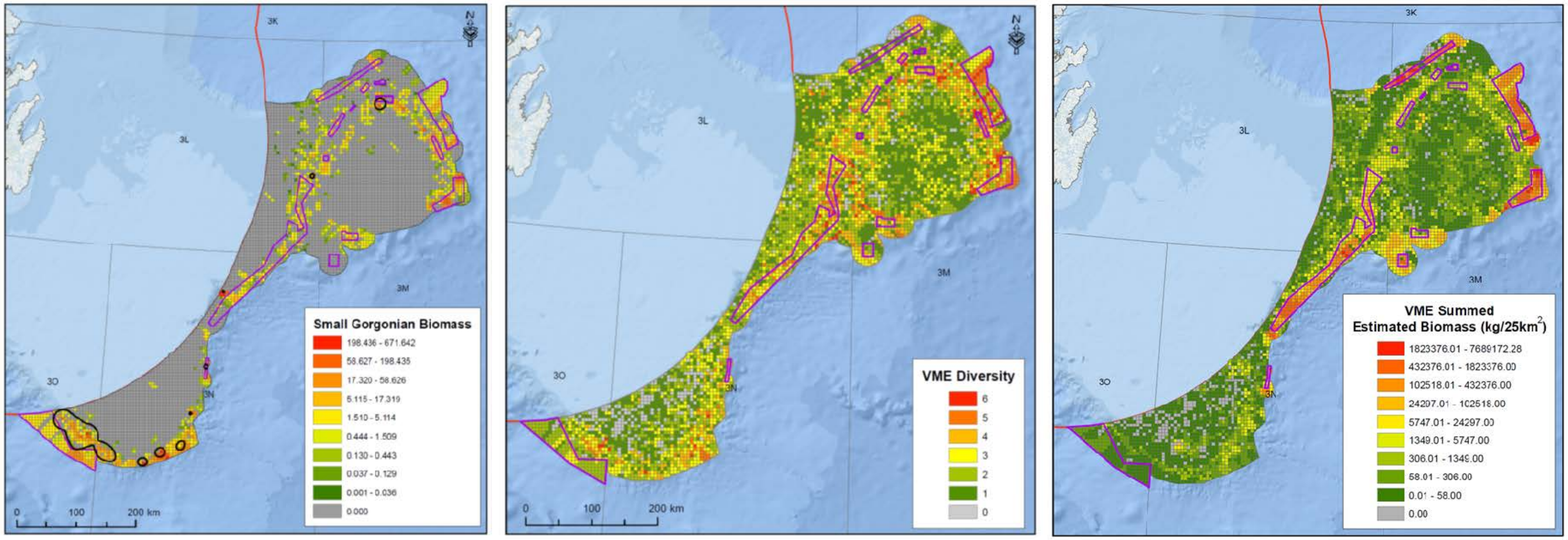

Figure 7.3 (cont'd). Gridded wet weight biomass (kg/25 km^2) for the VME Indicator taxa. Left and right: Small gorgonian corals and total VME biomass. Middle: Number of VME Indicator taxa per grid cell (maximum 7). VME polygons for the small gorgonian coral indicator taxon are outlined in black. Closed areas are outlined in purple.

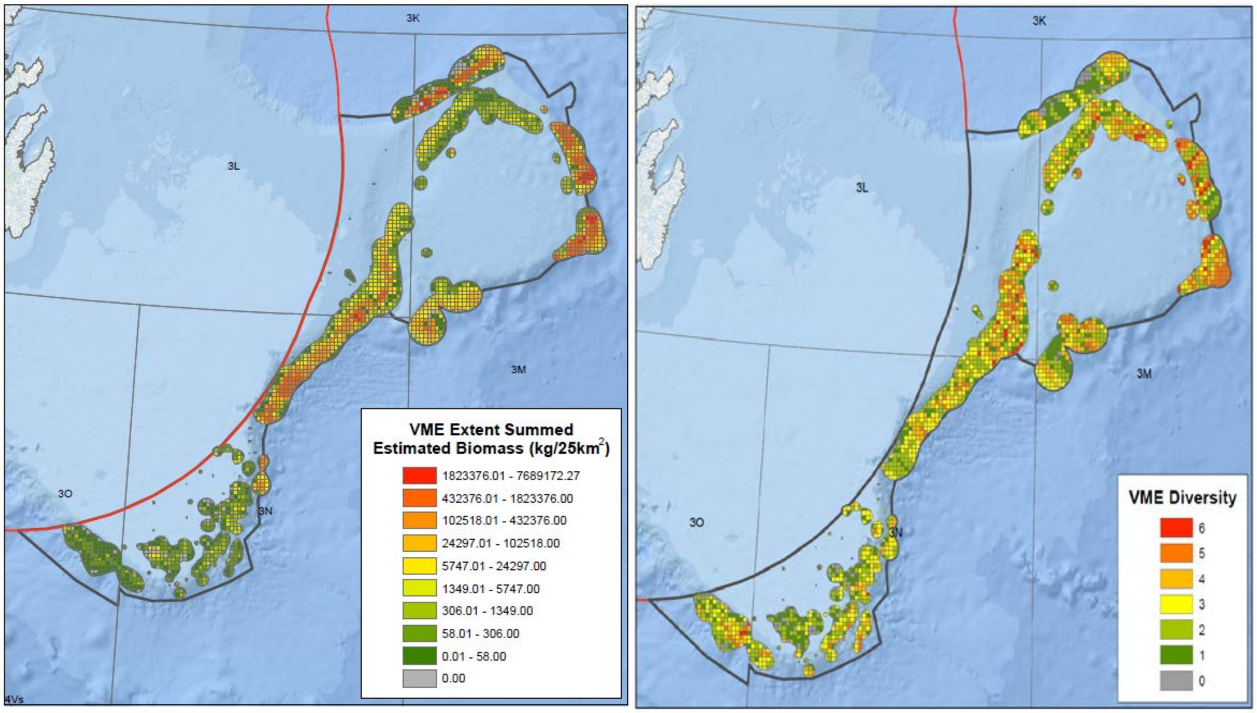

Figure 7.4. Left panel: The total wet weight biomass (kg) of all VME Indicators found per 25 km^2 grid cell inside the KDE-derived VME polygons (Kenchington *et al.*, 2019). Right panel: the number of VME Indicator groups per 25 km^2 grid cell inside the KDE-derived VME polygons (Kenchington *et al.*, 2019).

iv) Benthic functional polygon boundaries

At the 19-28 November 2019 meeting of the NAFO Working Group on Ecosystem Science and Assessment (WG-ESA) it was recognized that in order to evaluate the significance of fishing impacts on the benthos (and VMEs in particular) at the ecosystem level it would be desirable to have knowledge of the ecosystem functions of the benthos as a whole, so that specific SAI on VMEs could be evaluated and placed into a broader context (NAFO, 2020). Specific traits linked to four important ecological functions provided by benthic communities were identified for initial consideration: A) Bioturbation; B) Nutrient cycling; C) Habitat provision, and D) Functional diversity.

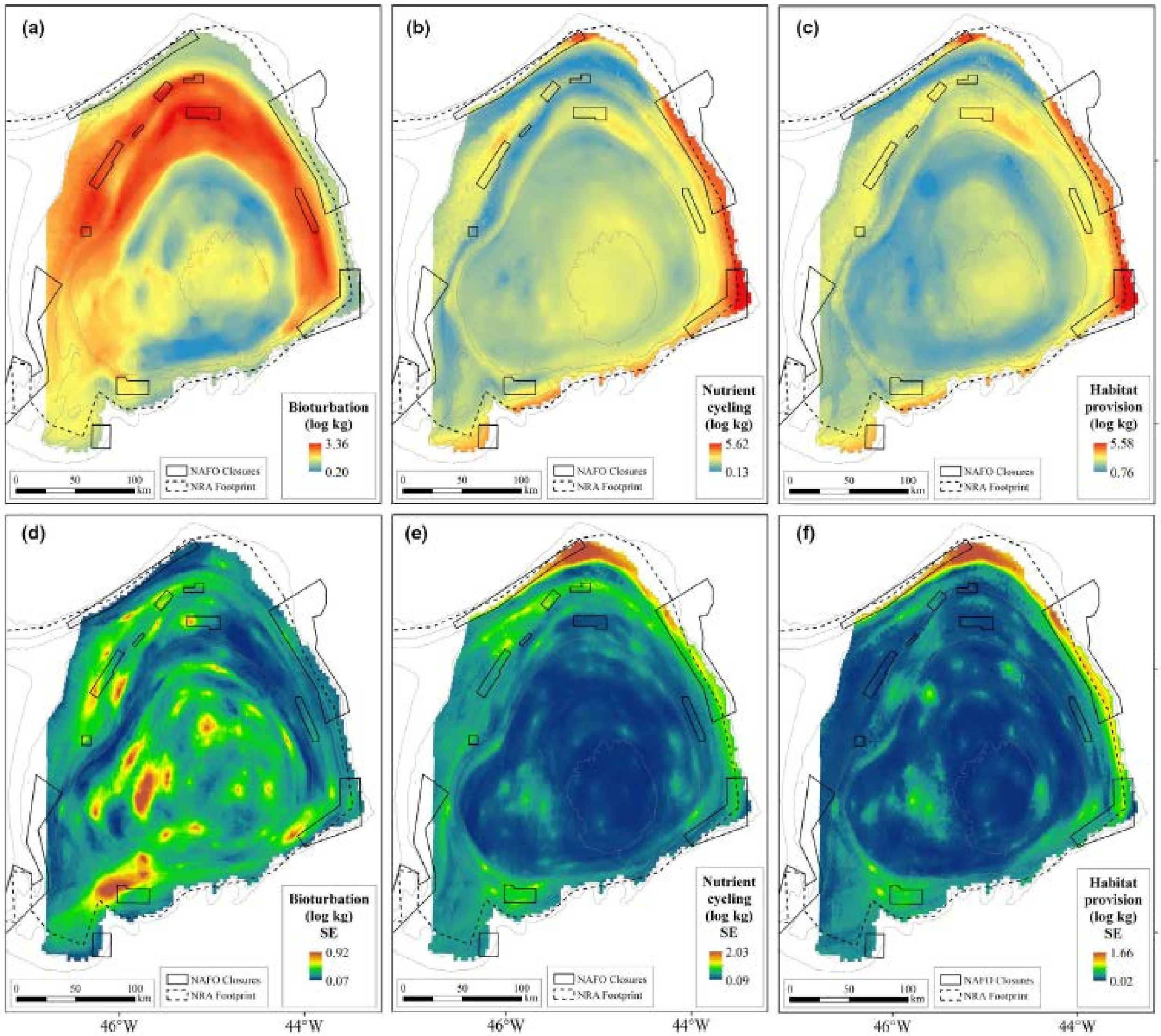

Figure 7.5. Predicted distribution maps created through random forest modeling of a) bioturbation, b) nutrient cycling and c) habitat provision with associated standard error (SE) for each surface reproduced from Figure 7 in Murillo *et al.* (2020a).

Murillo *et al.* (2020a) have analyzed and mapped these for the Flemish Cap ecosystem (Figures 7.5, 7.6) using data collected from the 2007 EU Flemish Cap bottom-trawl research survey, conducted by the Instituto Español de Oceanografía together with the Instituto de Investigaciones Marinas and the Instituto Português do Mar e da Atmosfera. The survey sampled the Flemish Cap and the eastern side of Flemish Pass between 138 and 1488 m depth, following a depth stratified random sampling design (Vázquez *et al.*, 2014; Murillo *et al.*, 2016). It was conducted on board the Spanish research vessel Vizconde de Eza, with standardized sets of a Lofoten bottom trawl, with a swept area of ≈0.04 km^2 each. A total of 288 taxa from 176 trawl sets were initially recorded, and the biomass (kg wet weight) for each was determined. Further taxonomic examination lead to a reduction of the total number to 285 discrete taxa.

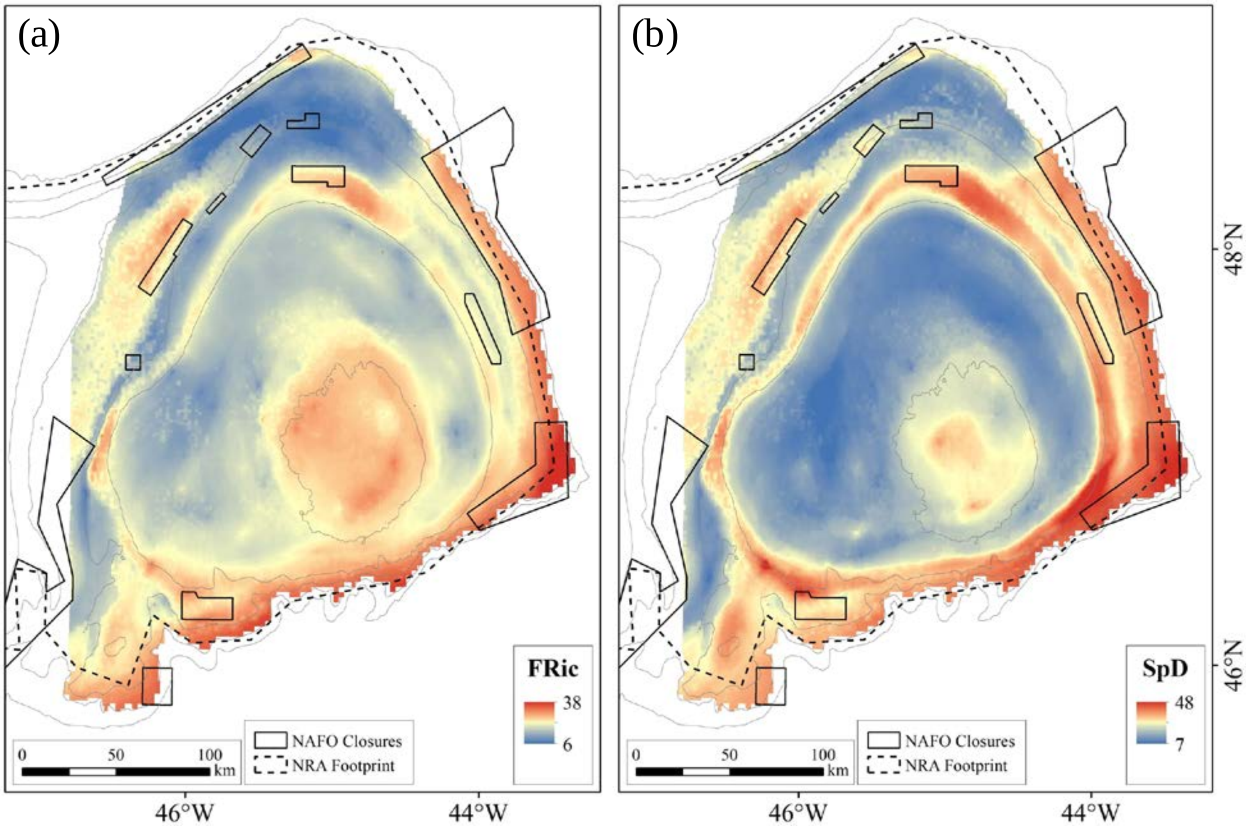

Figure 7.6. Predicted surfaces from random forest modelling of (a) sample functional richness (FRic), (b) sample species density (SpD) (modified from Murillo *et al.*, 2020b). Reproduced from Supplementary Figure S6.1 of Murillo *et al.* (2020a).

Here, we utilize a data set with a broader temporal coverage (10 years, Table 7.4), but with a lower taxonomic certainty, with most of the specimens having been identified at sea by multiple individuals over the time frame. For each ecosystem function (except for Functional Diversity) we assessed the presence or absence of the function for each taxon in the species lists for the respective cruises, using the available literature (Kenchington *et al.*, 2020). Functional diversity was not assessed due to time limitations.

The biomass data associated with these ecosystem functions contain records using different gear types and tow lengths (Table 7.4), with associated catchability differences, and different locations (NAFO Divisions) with different bottom types and depths, which could also affect catchability. To assess whether the different survey data should be used separately or in combination for each ecosystem function, we applied non-parametric statistics (Kolmogorov–Smirnov two sample test (K-S test)) to the catch biomass from each of the three gear/duration data sets for each function data set and for fish and invertebrates separately where relevant (Table 7.4). These were augmented with biomass accumulation curves for comparative data sets.

Table 7.4. Data sources from contracting party research vessel surveys: EU, European Union; DFO, Department of Fisheries and Oceans Canada; NL, Newfoundland and Labrador; EIO, Instituto Español de Oceanografía; IIM, Instituto de Investigaciones Marinas; IPMA, Instituto Português do Mar e da Atmosfera.

Programme	Period	NAFO Division	Gear	Mesh Size in Codend Liner (mm)	Trawl Duration (min)	Average Wingspread (m)	Depth Range (m) of Trawl Start Data
Spanish 3NO Surveys (IEO)	2011-2019	3NO	Campelen 1800	20	30	24.2-31.9	41-1462
EU Flemish Cap Surveys (IEO, IIM, IPIMAR)	2011-2019	3M	Lofoten	35	30	13.89	129-1460
Spanish 3L Surveys (IEO)	2011-2019	3L	Campelen 1800	20	30	24.2-31.9	106-1433*
DFO NL Multi-species Spring and Fall Surveys (DFO)	2011-2019	3LNO	Campelen 1800	12.7	15	15-20	38-725 (Spring) 36-1379 (Fall)

Kernel density estimation (KDE) utilizes spatially explicit data to model the distribution of a variable of interest. It is a simple non-parametric neighbour-based smoothing function that relies on few assumptions about the structure of the observed data. It has been used in ecology to identify hotspots, that is, areas of relatively high biomass/abundance. It was first applied within NAFO to the identification of significant concentrations of sponge biomass in the NRA in 2009 (Kenchington *et al.*, 2009) followed by an application to sea pen biomass (Murillo *et al.*, 2010). Since then it has been applied to the catch biomass of all VME Indicator taxa to identify VMEs (Kenchington *et al.*, 2019). In applying the KDE to the trait data herein we have followed the same approach as used previously to identify the VME polygons, that is, we used biomass data. Running KDE analyses using the biomass of different size classes of organisms, as was done for the invertebrates and fish for bioturbation, could be one way of examining how well the KDE polygons constructed here, capture areas important to organisms with smaller biomass given these issues with abundance data. However, KDE is a spatial analysis and so aspects of abundance correlated to the area occupied may be captured in addition to correlations with biomass. Nevertheless, abundance can be very important for other aspects of ecosystem functioning, such as population dynamics, and KDE analyses using that variable for selected taxa is something that can be explored in future work. A fuller discussion of the rationale behind the use of biomass data is presented in Kenchington *et al.* (2020). Here, our purpose was to identify significant concentrations of the biomass for each ecosystem function so that the KDE polygons created for the VMEs (Kenchington *et al.*, 2019) could be overlain and the relative area occupied compared. For that reason too, biomass had to be used to render the areas comparable. The default search radius was used based on the spatial extent of the data and only adjusted if there were gaps in the coverage (see details in Kenchington *et al.*, 2020). We performed the analyses separately for the different surveys based on an assessment of the catch data so that catchability issues are reduced. The resultant KDE polygons were then presented together in a single map to appreciate the full spatial extent of the significant biomass concentrations for each of the traits in the NRA. Full details of each analyses, including figures and tables, are in Kenchington *et al.* (2020).

Bioturbation

Sediments play a key role in the exchange of nutrients in marine ecosystems and in the marine nitrogen cycle in particular, where they influence global biogeochemical cycles (Laverock *et al.*, 2011). Bioturbation, defined here as "the mixing of a sediment by the burrowing, feeding or other activity of living organisms, forming a bioturbated sediment" (Froese & Pauly, 2000), affects ecosystem functions and properties such as energy and nutrient cycling, habitat stability/vulnerability and habitat heterogeneity (Degen *et al.*, 2018). Deposit feeding and ventilation of burrows by infauna are two of the most common and widespread bioturbation processes (Shull, 2009). The activity of large burrowing macrofauna (bioturbators) in soft sediments can significantly affect microbial processes associated with remineralisation by altering the properties of the sediment, principally through oxygenation (Queirós *et al.*, 2013). Fish (Villéger *et al.*, 2017) and marine mammals can also cause bioturbation through the construction of burrows and through their foraging and defense behaviours (Shull, 2009). Examples include the sand lance (*Ammodytes dubius*, Ammodytidae) which burrows into the sand or gravel (Scott, 1973; Staudinger *et al.*, 2020), and walruses which dig in the sediments for molluscs (Ray *et al.*, 2006).

Herein, adult-stage bioturbation trait presence/absence was assessed for each of the recorded taxa in the research vessel catches conducted by Canada and the EU. We used the comprehensive assessments of Queirós *et al.* (2013) for European marine infaunal invertebrates (N=1033), Murillo *et al.* (2020a) for epibenthic species from Flemish Cap (N=285), Sutton *et al.* (2020) for epibenthic species from the Beaufort (N=246) and Chukchi Seas (N=247), and Kaminsky *et al.* (2018) for the San Jorge Gulf, Argentina (N=61), in addition to literature searches for species not covered by those sources. Details are provided in Kenchington *et al.* (2020) [see Appendices 1 and 2 therein].

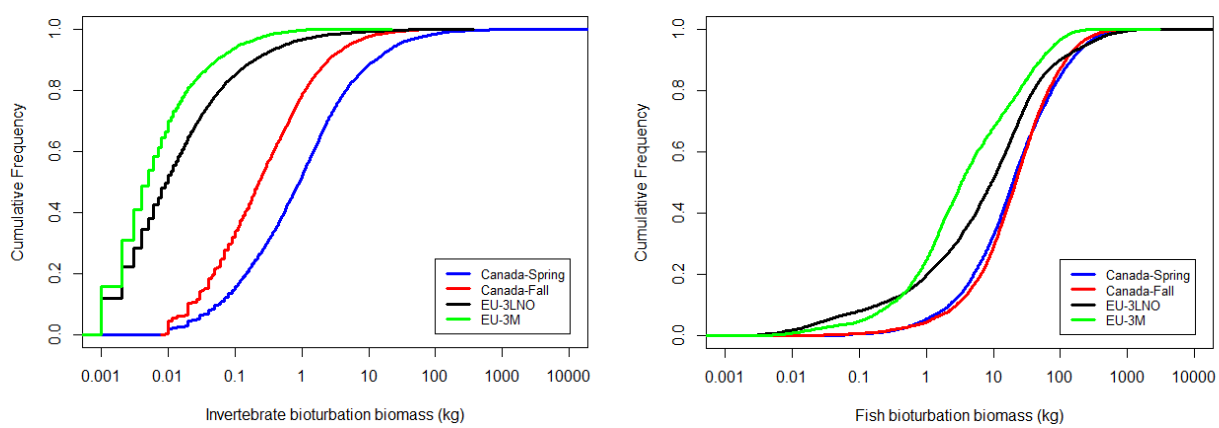

Figure 7.7. Cumulative bioturbator biomass distribution for invertebrates (left) and fish (right) for each of the four surveys from which data were collected (Table 7.4).

Analyses of the bioturbator biomass data showed significant differences between the spring and fall surveys in Canada, and with tow length using the Campelen 1800 gear for both fish and invertebrates. The two Canadian surveys also differed in depth. Cumulative biomass distribution plots (Figure 7.7) show that for fish the two Canadian surveys, one conducted in the spring and one in the fall in the same area with the same gear, are very similar throughout their biomass distributions, unlike for the invertebrates. Note that the two EU surveys of 3L and 3NO were combined for these analyses. Coznsequently, we have combined the Canadian spring and fall surveys for the KDE analyses for the fish and kept the other surveys separate. This produced the following data sets for KDE analyses:

1. EU surveys invertebrate data 3M, 30 min tow length, depth range 132-1478 m;
2. Canadian invertebrate data 3LNO, 15 min tow length, spring, depth range 38-725 m;
3. Canadian invertebrate data 3LNO, 15 min tow length, fall, depth range 36-1333 m;
4. EU surveys invertebrate data 3LNO, 30 min tow length, depth range 40-1429 m;
5. EU surveys fish data 3M, 30 min tow length, depth range 129-1460 m;
6. Canadian fish data 3LNO, 15 min tow length, depth range 36-1379 m;
7. EU surveys fish data 3LNO, 30 min tow length, depth range 40-1433 m.

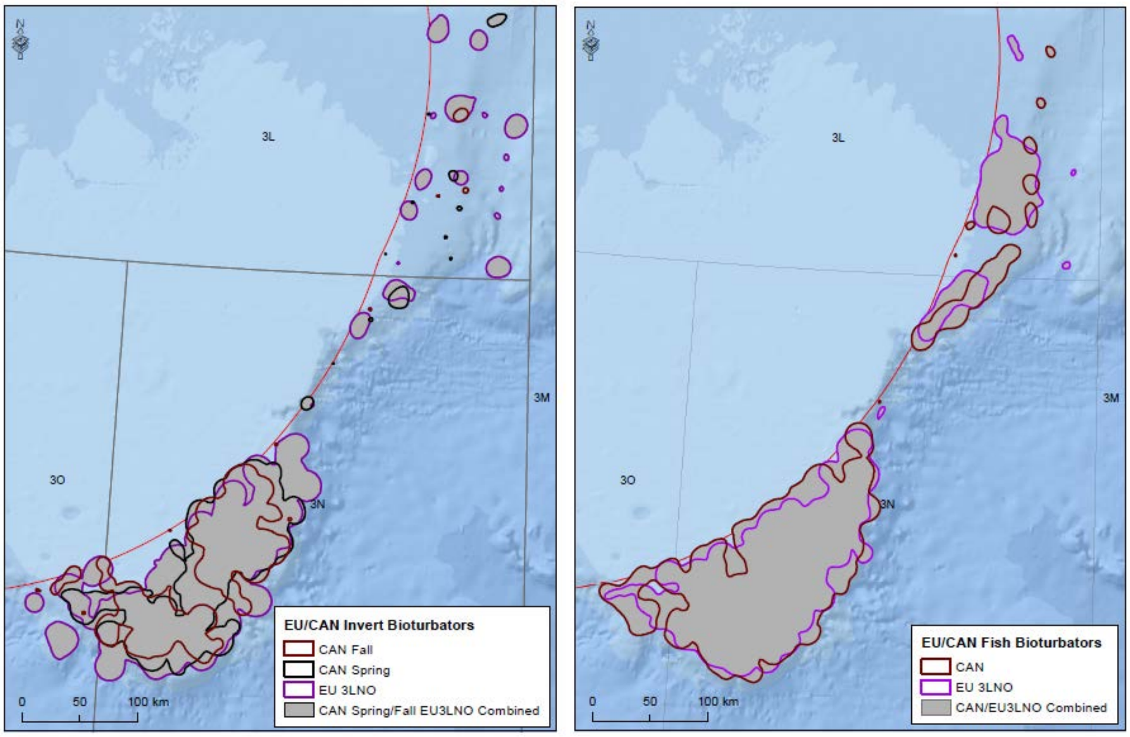

Figure 7.8. The kernel density polygons of high concentrations of invertebrate (left panel) and fish (right panel) bioturbation biomass in the NRA 3LNO based on analyses of Canadian (red/black) and EU (purple) Survey data. The grey area shows the combined area from both surveys. Trawl positions from the 3LNO surveys with invertebrate bioturbator catch are shown in Kenchington *et al.* (2020), Figure 18.

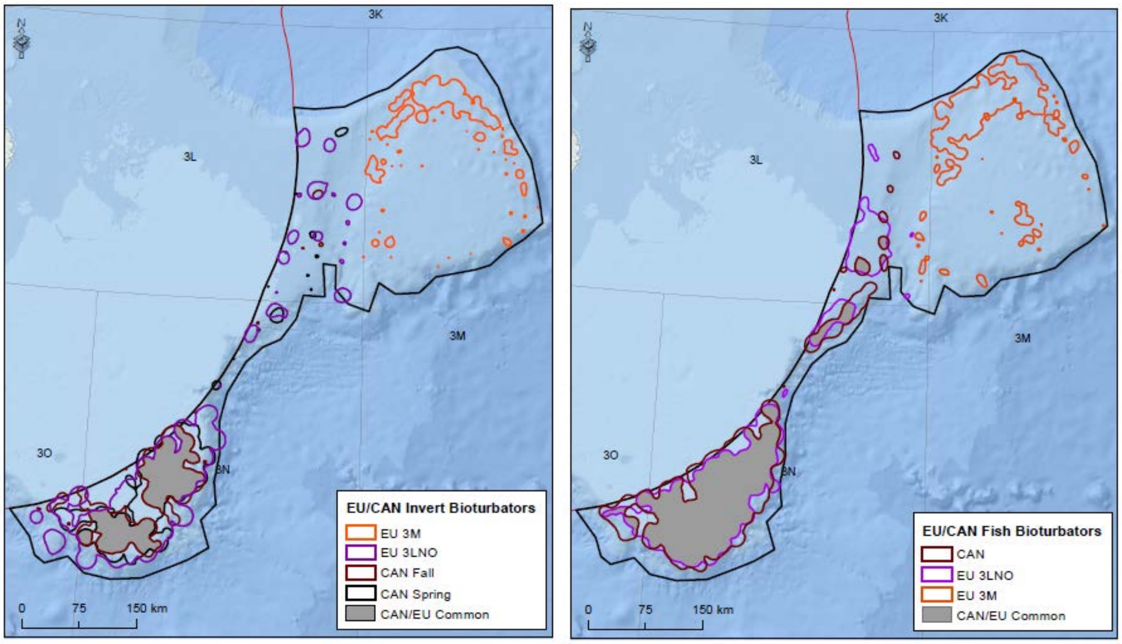

Figure 7.9. The kernel density polygons of high concentrations of invertebrate (left panel) and fish (right panel) bioturbation biomass in the NRA based on analyses of Canadian (red/black) and EU (orange/purple) survey data. The grey area shows the common area from the surveys in Divisions 3LNO (Canadian spring, fall and EU for invertebrates and Canadian and EU for fish).

Figures 7.8 and 7.9 show the combined results of the kernel density analyses for significant concentrations of invertebrate and fish bioturbation biomass in the NRA. For both EU and Canadian surveys the Tail of Grand Bank has high concentration of bioturbation biomass, indicating that this area is likely important for remineralisation and other geochemical processes. The northern slopes of Flemish Cap also have significant biomass associated with bioturbation. Although both the fish and invertebrate bioturbation biomass are in similar areas, the area covered by the fish is broader and less detailed, possibly reflecting their mobility.

For the invertebrate taxa, all three surveys in Divisions 3LNO (Canadian spring, fall and EU) identified the sea cucumber, *Cucumaria frondosa*, as the top species contributing to the catches which delineated the KDE polygons. The brittlestar *Ophiura sarsii* was common to the higher-ranking taxa in all three surveys and the sand dollar *Echinarachnius parma* ranked highly in the Canadian spring surveys and the EU surveys. All three are considered surficial modifiers, causing bioturbation in the upper centimetres of the sea bed. As biomass drives these KDE analyses it appears that the differences in area between the 3LNO KDE polygons for invertebrate bioturbation are related to the location of the trawl sets rather than to large differences in species composition – although there are species that are uniquely found in the deeper sets, or are more prevalent there. This area contrasts sharply with the top-ranking species on Flemish Cap, where two VME indicator sea pens, *Anthoptilum grandiflorum* and *Halipteris finmarchica* contribute most to the biomass and influence the delineation of the KDE invertebrate bioturbation polygons there. These results are consistent with the Flemish Cap being a unique ecosystem in terms of its benthos (Murillo *et al.*, 2016).

A similar pattern is seen in the comparison of the top-ranking bioturbating fish species. In Divisions 3LNO both Canadian and EU surveys identify the same four top ranking species, with only the relative positions of the third and fourth ranking species differing. In both, *Limanda ferruginea* is the top-ranking contributor to the biomass that delineated the fish bioturbation polygons. Again, Division 3M has a different top ranking species list. *Reinhardtius hippoglossoides* dominates the biomass along with other Pleuronectidae. Most of these species are surficial modifiers, disturbing the upper surface of the sediment as they feed and bury in the sediments to conceal themselves. However, the burrowing sand lance, *Ammodytes dubius*, a top contributor to biomass in Divisions 3LNO, burrows in the sand to a depth of several inches (7.5 cm) (Nizinski *et al.*, 1990). Details of the species contributing most to the bioturbator biomass within the KDE polygons, by survey, are provided in Kenchington *et al.* (2020) [see Appendices 3 to 10 therein].

Nutrient Cycling

Nutrient exchange between the productive surface waters and the benthos is effected through a number of different pathways in marine ecosystems and supports essential ecosystem functions such as energy transfer in food webs and biogeochemical cycling (Griffiths *et al.*, 2017; Agnetta *et al.*, 2019). Benthic species have a diversity of feeding guilds, which have been classified variously in the literature over many decades.

Here, we have focused on the benthic filter-feeding species found in the NRA. There are two general categories of filter feeders: 'passive' filter feeders depend entirely on ambient water flow to supply particles to their feeding structures (*e.g.*, corals); and 'active' suspension feeders create their own feeding current to enhance the local supply of food particles (*e.g.*, sponges, crustaceans, and bivalve molluscs) (Goldberg, 2018). Some others, such as some barnacles, utilize both strategies. Details are provided in Kenchington *et al.* (2020) [see Appendices 11 and 12 therein].

Analyses of the nutrient cycling biomass data showed significant differences between the spring and fall surveys in Canada, and with tow length and NAFO Division using the Campelen 1800 gear (Kenchington *et al.*, 2020). Cumulative biomass distribution plots (Figure 7.10) show that the two Canadian surveys, one conducted in the spring and one in the fall in the same area with the same gear but different maximum depth (Table 7.4), are very similar, as was the case for the fish bioturbators. Consequently, the Canadian data for the nutrient cyclers were combined for the KDE analyses and the other surveys were kept separate. This produced the following data sets for KDE analyses:

1. Canadian data 3LNO, 15 min tow length, depth range 36-1379 m;
2. EU surveys data 3LNO, 30 min tow length, depth range 43-1462 m;
3. EU surveys data 3M, 30 min tow length, depth range 132-1460 m.

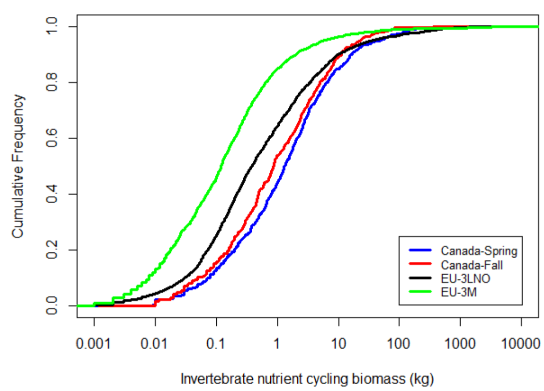

Figure 7.10. Cumulative nutrient cycling biomass distribution for invertebrates for each of the four surveys from which data were collected (Table 7.4).

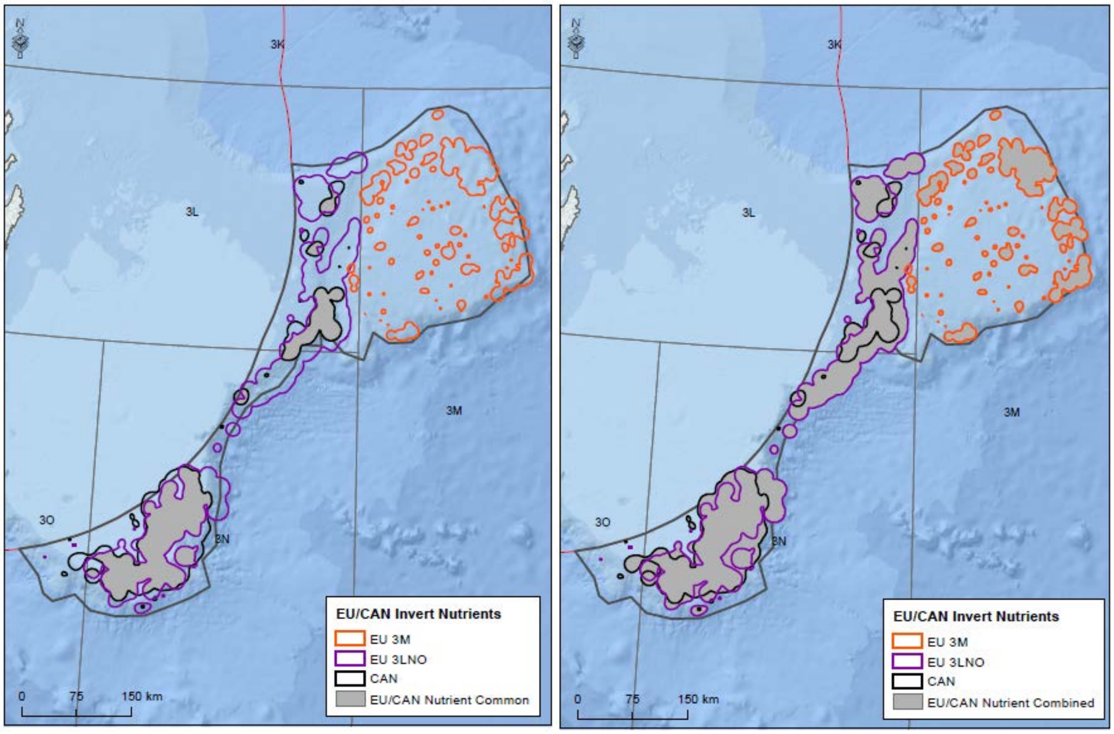

Figure 7.11. The kernel density polygons of high concentrations of invertebrate nutrient cycling biomass in the NRA based on analyses of Canadian (black) and EU (orange/purple) survey data. Left panel: The grey area shows the common area from both Canadian and EU surveys in Divisions 3LNO. Right panel: The grey area shows the full area of high concentration of nutrient cycling in the NRA from the three surveys combined. The fishing footprint perimeter is shown as a solid grey line and approximates 2000 m.

Figure 7.11 shows the combined results of the kernel density analyses for significant concentrations of invertebrate nutrient cycling biomass in the NRA. This activity is widespread throughout the NRA, indicating that many areas are important for benthic-pelagic coupling. Where the bioturbation activity is restricted to soft bottoms, nutrient cycling occurs on both soft and hard bottoms and so has a broader potential occupancy extent.

Both the Canadian and EU surveys of NAFO Divisions 3LNO identified the large-sized, massive, sponges (all active filter-feeders) and the sea cucumber, *Cucumaria frondosa* (a passive filter-feeder), as comprising the top 90% of the biomass in the catches that were used to delineate the KDE polygons. The Canadian surveys recorded the sponges only as ‘Porifera' while the EU surveys identified *Geodia* spp., and other Astrophorids as the taxa involved. The VME Indicator taxon, *Boltenia ovifera*, ranked high in biomass in both surveys (Appendices 13, 14 of Kenchington *et al.*, (2020)) which, given that it does not have a high individual weight, suggests that it is abundant in some areas.

A similar result was found on Flemish Cap (Division 3M), where these same sponge taxa dominated the biomass (Kenchington *et al.*, 2020), although there, some sea pens were highly ranked as well. Unlike the bioturbators, nutrient cyclers are heavily dominated by VME Indicator taxa accounting for at least 77% of the biomass in the catches above the threshold established in 3LNO and 93% of that in 3M.

As noted for the bioturbation KDE polygons, the polygons created from data collected by the EU Surveys in Divisions 3LNO include trawl sets in deeper water and so provide valuable data for those areas. In this case the depth ranges are similar for both surveys (36 - 1 379 m for Canadian surveys and 43 - 1 462 m for EU surveys) but there were only seven (7) trawl sets greater than 750 m in the Canadian data set and 161 trawl sets in the EU survey data set. There were no depth gaps in the EU survey, with sets recorded in every 100 m depth bin within the depth range. In the Canadian surveys there were no stations in the nutrient data set that fell between 800-900 m and between 1 000-1 100 m.

As noted, the species compositions are not directly comparable between EU and Canadian surveys in Divisions 3LNO, as the EU species list is more detailed. Of the two dominant taxa reported in each, sponges and the sea cucumber *Cucumaria frondosa*, the Canadian surveys record Porifera at all sampled depth ranges (n=101 sets), while the EU surveys record Porifera across the depth range (47-1462 m, n=262 sets) but the *Geodia* (n=38 sets), Geodiidae (n=49 sets) and Astrophorina (n=52 sets) are all deeper living (649-1462 m, 790-1399 m, and 657-1399 m respectively). The greater number of deep water sets in the EU surveys, largely in the deep Flemish Pass, will mean that the KDE polygons covering those areas will have a predominance of the *Geodia*-type massive sponges.

In contrast, *Cucumaria frondosa* was recorded at all sampled depth ranges in the Canadian surveys between 39 and 684 m (n= 118 sets). In the EU surveys this species was only recorded between 43 and 271 m (n=117 sets). Therefore the common area on the Tail of Grand Bank between these surveys would have a greater influence of this species in the Canadian data between 271 and 684 m. None of this affects the analyses but rather helps to understand what is driving the KDE results. Details of the species contributing most to the nutrient cycling biomass within the KDE polygons, by survey, are provided in Kenchington *et al.* (2020) [see Appendices 13 to 15 therein].

Habitat Provision

Marine biogenic habitats, such as cold-water coral gardens and sponge grounds are created by living organisms that form three-dimensional structures that create niches for other species and thereby locally enhance biodiversity. The United Nations General Assembly resolutions calling for the protection of Vulnerable Marine Ecosystems highlight the biodiversity that such areas contain. For a VME indicator to qualify as a VME, it should be present in significant concentrations (habitat forming), or in the case of uniqueness or rarity, be associated with an area or ecosystem whose loss could not be compensated for by similar areas or ecosystems elsewhere (FAO, 2009). Identification of what species/habitats qualify as VME indicators is based on five criteria established by FAO in 2009:

1. Uniqueness or rarity;
2. Functional significance of the habitat;
3. Fragility;
4. Life history traits of the component species that make recovery difficult;
5. Structural complexity.

The VME indicator species in NAFO (NAFO, 2021) were mostly identified on the basis of the 5th criterion, structural complexity (Murillo *et al.*, 2011), and so would meet our definition of habitat provision applied herein. Details of the species included as habitat providers are found in Kenchington *et al.* (2020) [see Appendices 16 and 17 therein].

Analyses of the habitat provision biomass data showed no significant differences between the spring and fall surveys in Canada, and so those two surveys of Divisions 3LNO were combined. This is supported by the cumulative biomass curves for those two surveys (Figure 7.12). Significant differences were found with tow length and NAFO Division using the Campelen 1800 gear. Cumulative biomass distribution plots (Figure 7.12) show that the two EU surveys are different from each other and from the Canadian surveys. Consequently the

Canadian data were combined for the KDE analyses and the other surveys were kept separate. This produced the following data sets for KDE analyses:

1. Canadian data 3LNO, 15 min tow length, depth range 39-1333 m;
2. EU surveys data 3LNO, 30 min tow length, depth range 42-1433 m;
3. EU surveys data 3M, 30 min tow length, depth range 132-1460 m.

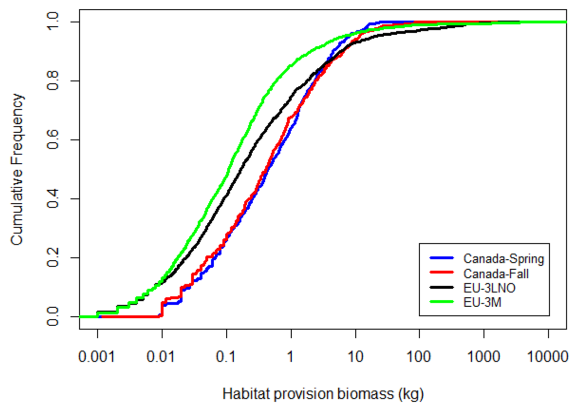

Figure 7.12. Cumulative habitat provision biomass distribution for invertebrates for each of the four surveys from which data were collected (Table 7.4).

Figure 7.13 shows the combined results of the kernel density analyses for significant concentrations of invertebrate habitat provision biomass in the NRA. The concentrations are found along the slopes of Grand Bank and Flemish Pass as well as on the Flemish Cap. In all three surveys, the catches which delineated the KDE polygons were dominated by large-sized sponges – *Geodia* spp. and other Astrophorids, as well as unidentified Porifera. In Divisions 3LNO, the sea squirt *Boltenia ovifera* and the soft coral *Duva florida* comprised the highest biomass for non-sponge taxa in both Canadian and EU surveys, while in Division 3M, *Duva florida*, the sea pen *Anthoptilum* and the large gorgonian corals *Paragorgia* were among the highest ranking non-sponge biomass. Because the VME Indicator taxa were part of the selection criteria for this trait, they dominate the biomass in the habitat provision KDE polygons. As for the other traits, the EU surveys in Divisions 3LNO are more frequent in deeper water (Figure 7.13), particularly in the deep Flemish Pass, and the deep slopes of Grand Bank. The depth range of the EU Surveys was 44 - 1 462 m for the trawl locations used to delineate the KDE polygons, and sets were found in every 100 m depth bin. Of those, 219 were in water greater than 750 m. Whereas the Canadian survey data also covered a range of 39 – 1 333 m (with gaps between 800-900 m and 1 000-1 100 m depth bins), only 9 tows were in water greater than 750 m. Porifera was recorded in Canadian and EU sets throughout the full depth range of each survey (n=349 sets and n=397 sets, respectively), and so there was no strong bias in species composition between them. However, the EU surveys recorded *Geodia* and Astrophorina only in the deeper sets below 649 and 458 m respectively, along with the sea pens and large and small gorgonian corals. The EU surveys consequently identify important areas of habitat provision, largely in sponge dominated areas and sea pen fields, in deeper water. See Kenchington *et al.* (2020), Appendices 18 to 20, for more details.

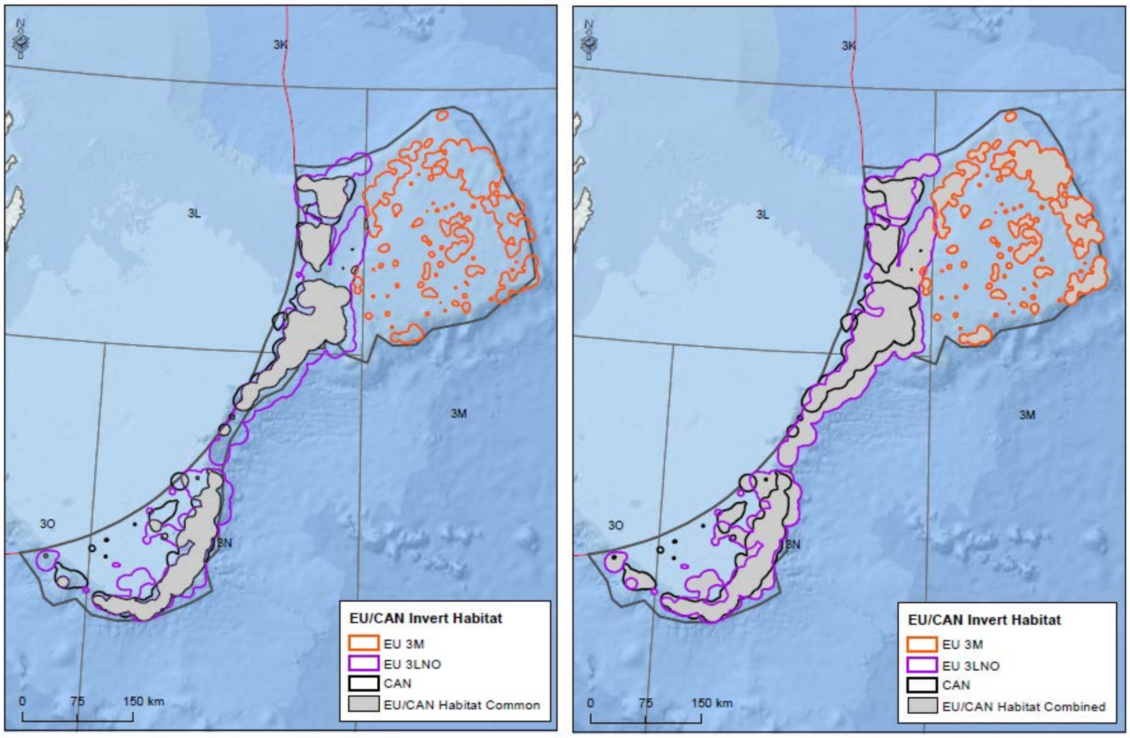

Figure 7.13. The kernel density polygons of high concentrations of invertebrate habitat provision biomass in the NRA based on analyses of Canadian (black) and EU (orange/purple) survey data. Left panel: The grey area shows the common area from both Canadian and EU surveys in Divisions 3LNO. Right panel: The grey area shows the full area of high concentration of nutrient cycling in the NRA from the three surveys combined. The fishing footprint perimeter is shown as a solid grey line and approximates 2 000 m.

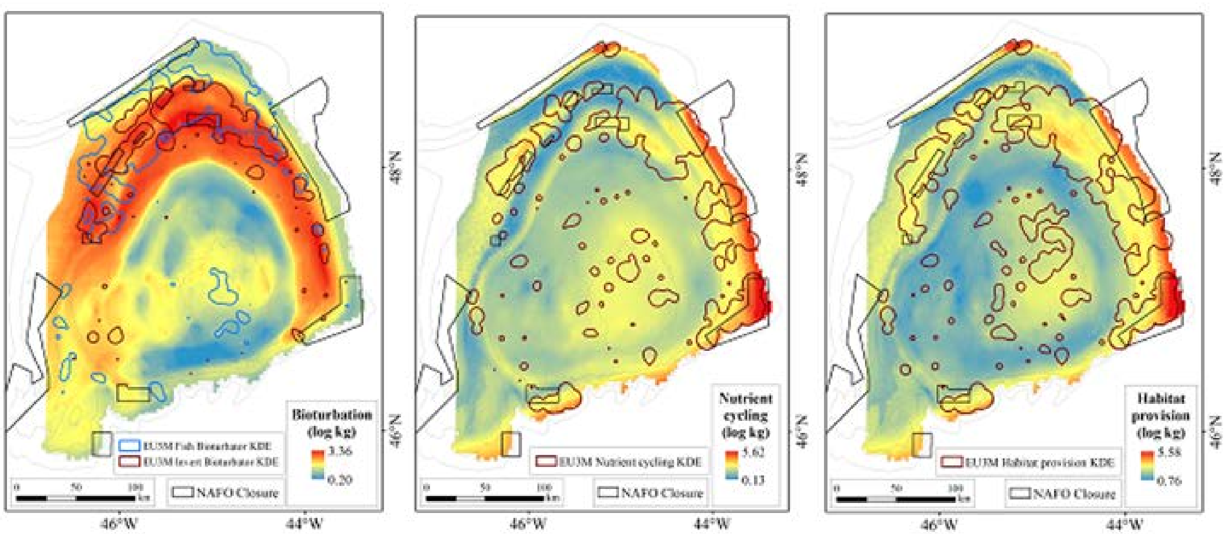

Figure 7.14. KDE Polygons for bioturbation, nutrient cycling, and habitat provisions for NAFO Division 3M overlain on the random forest models for those traits from Murillo *et al.* (2020a).

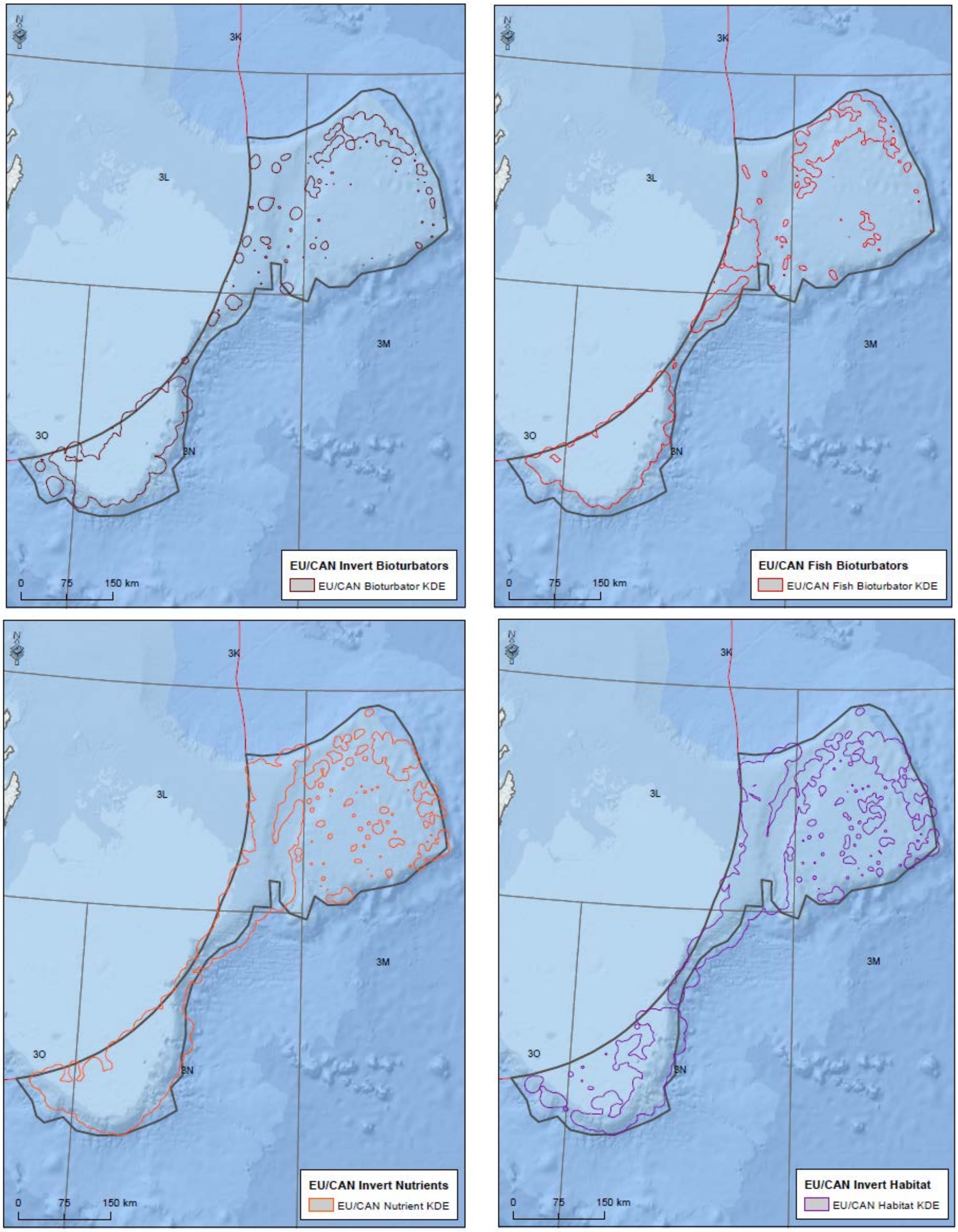

Figure 7.15. KDE polygons showing areas of high biomass for invertebrate bioturbation (upper left), fish bioturbation (upper right), nutrient cycling (lower left) and habitat provision (lower right).

Conclusions

The kernel density analyses appears to have performed well when applied to the catch biomass of the various taxa that contributed to each of the ecosystem functions assessed (bioturbation, nutrient cycling and habitat provision). For Division 3M we were able to directly compare our results with those of Murillo *et al.* (2020a) (Figure 7.14) and there is a good correlation between the areas identified using both methods (KDE vs. SDM), despite the difference in time frame over which the data were collected (9 years vs. 1 year). Mapping of the functional trait diversity in the NRA facilitates the mainstreaming of ecosystem services into policy and decision making (Maes *et al.*, 2012). Here we have produced maps of key areas (KDE polygons) for three ecosystem services (Figure 7.15). The areas are large, but reflective of the importance of the benthic compartment in ecosystem functioning. These maps can be used to contextualize the impacts of bottom contact fishing gear on VMEs which contribute to all three ecosystem services examined.

v) VME closure buffers

Fisheries & Oceans Canada defines buffer zones in relation to marine protected areas (MPAs) as: "areas defined around the MPA to protect it from unnecessary encroachment of human activities that may damage important species or habitats of the MPA's ecosystem. Uses within buffer zones are managed in a manner that conserves and protects the marine resources and habitats within the MPA." (https://www.dfo-mpo.gc.ca/oceans/publications/mpaframework-cadrezpm/index-eng.html accessed 23/11/2020). In the context of the protection of VMEs from significant adverse impacts of bottom-contact fishing gears (SAI; *sensu* FAO, 2009), ICES considers a buffer zone to be "a spatial margin of assurance around the VME to avoid adverse impact" (ICES Advice, 2013). ICES advises to consider buffer zones when establishing closures around VMEs in order to avoid SAI (ICES Advice, 2013).

Such buffer zones should consider both uncertainty in the location of the fishing activity and/or the VME, as well as the indirect impacts of trawling (*e.g.*, re-suspended sediments) when such activities occur in close proximity to the protected area (Grant *et al.*, 2019). It may also be important to consider any issues related to enforcement (ICES Advice, 2013). A non-exhaustive survey of buffer zones applied by different bodies is presented in Table 7.5.

Currently, the NAFO closed areas to protect coral and sponges, and the VME polygons established using kernel density analysis and modified in some cases using species distribution models do not incorporate explicit buffer zones.

Buffer zones based on the uncertainty associated with the location of the fishing and/or the VME

ICES guidelines on calculating the buffer zone size were first presented in 2013 (ICES, 2013) and are used regularly when delineating proposed closures. The key consideration taken for determining their recommendations for buffer zones are the **VME location accuracy** considering the uncertainty of the gear's location related to the vessel position. For data collected from research or commercial trawls this is a function of the gear's warp length and of the depth. The location accuracy was defined by the accuracy of the method used to estimate the coordinates of the VME, for example, it may be a precise point estimated with video surveillance equipment, a commercial or survey trawl track resulting in a significant catch of the indicator species, or a polygon identified as a VME area (Figure 7.16).

As a result the 2013 ICES advice was: "For VMEs that occur on flat or undulating seabed a buffer zone of approximately two (>500 m depth) or three times (< 500 m depth) the local depth is advised." (ICES Advice, 2013).

Subsequently, ICES considered that a closure boundary may encompass several VME locations and their buffer zones, if the distance between them is not greater than 3.5 nm, keeping its shape with as few vertices as possible, *i.e.*, the 'minimum distance spacing' approach (ICES, 2016). This was based on the accuracy of vessel position: assuming a vessel speed (when bottom fishing) of between 3–3.5 knots, the vessel will travel no more than 3.5 nautical miles in one hour. Thus, 3.5 nautical miles (nm) could be considered a minimum distance criterion for uniting the VME encounter locations within a single bottom fishing closure, as such small spaces between closed areas would not be practical to fish.

Implementation of this method led to the addition of extra width to the buffer zone determined by depth, based on the distance between the commercial vessel and the towed gear associated with the fishing operation

(ICES, 2017). Together, both aspects of the buffer zone (VME position accuracy and Commercial vessel trawl position accuracy) are currently used by the ICES advice process and the NEAFC management measures. For example, the buffer zone recommendation from the ICES Working Group on Deep-water Ecology for the Hatton-Rockall Basin was: "Boundary drawn around the area of sensitive seabed habitat with a total buffer of 3 900 m (1 500 m + (2 x 1 200 m))", with the 1 500 m associated with the positional accuracy of the record and the 1 200 m associated with the depth of the VMEs (ICES, 2017).

Table 7.5. Examples of buffer zones in use to protect VMEs.

Advisory Body	**Buffer Zone Recommendation for Closed Areas**	**Reference**
Buffer Zones Based on the Uncertainty Associated with the Location of the Fishing and/or the VME		
ICES	For VMEs that occur on flat or undulating seabed a buffer zone of approximately two (>500 m depth) or three times (< 500 m depth) the local depth is advised.	ICES Advice (2013); ICES (2013)
ICES	Positional accuracy of the record added to the depth buffer (ICES Advice, 2013).	ICES (2017)
ICES	½ C-square buffer as an appropriate buffer to ensure the protection of VME habitats distributed along the edge of the C-squares containing VMEs in EU waters (approx. 7.5 km).	ICES Advice (2020)
Buffer Zones Based on Sediment Transport Models or Similar Estimates of Indirect Impacts		
	A buffer of > 2.39 km for preventing any anthropogenically-re-suspended sediment from reaching the concentration thresholds of sponges in Hecate Strait, British Columbia.	Grant *et al.* (2019)
Buffer Zones Associated with Encounter Protocols		
CCAMLR	Australia proposed the use of 5 nm buffer zones around the location of the observations is proposed to mitigate the risk of spatial uncertainty in the notified position and the deployment of bottom-fishing gear.	SC-CAMLR-XXVII/13 (https://www.ccamlr.org/en/sc-camlr-xxvii/13 accessed 23/11/2020)
SEAFO	Master ceases fishing, moves at least 2 nm from end of trawl tow, defining a buffer area 2 nm radius, 1 nm for other gears (Articles 8.1 b-i and b-ii).	
SPRFMO	Master ceases fishing within 1 nm of trawl track (Article 28a).	
NPFC	Master ceases bottom fishing and moves no less than 2 nm, so that additional encounters with VMEs unlikely.	
NEAFC	Master ceases fishing, moves at least 2nm, reports the encounter to the Executive Secretary (Article 8.1, b-iii)	
NAFO	Fishing master reports the encounter, ceases fishing, moves at least 2nm from the endpoint of the tow/set	

Most recently, ICES has applied a ½ C-square buffer as an appropriate buffer to ensure the protection of VME habitats distributed along the edge of the C-squares containing VMEs in EU waters (ICES Advice, 2020). The C-square level resolution of 0.05° latitude x 0.05° longitude (approximately 15 km^2) is the spatial scale for which ICES receives VMS data from its member states, and its application was considered to be more straightforward than the more complex advice described above.

Buffer zones based on encounter protocols

RFMOs have buffer zones associated with their 'move-on rules' for VME encounter protocols. They tend to be 1 or 2 nm (Table 7.5) from the VME indicator observation and incorporate some concept of VME positional accuracy.

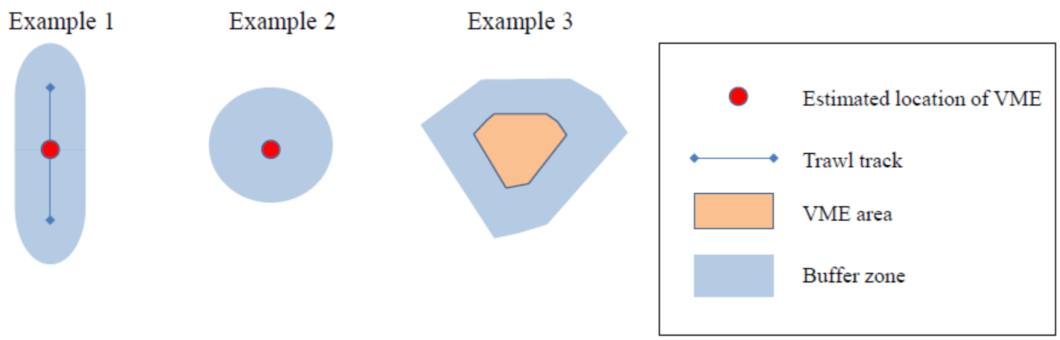

Figure 7.16. Conceptual examples of closures with buffer zones depending on the method used for estimating the VME location; Example 1 covers a trawl track (low accuracy), Example 2 – a precise point (high accuracy), Example 3 – a polygon area. [Figure from ICES Advice (2013)].

Buffer zones based on estimates of indirect effects of bottom trawling

Remobilization of sediments associated with bottom trawling is a potential risk to filter-feeding VME indicators causing smothering which can cause stress and even death (Grant *et al.*, 2019). Work undertaken in British Columbia, Canada has used sediment transport models (Boutilier *et al.*, 2013; Grant *et al.*, 2019) to estimate the footprint of the sediment plume in order to recommend buffer zones around areas closed to protect glass sponges. The later models were informed by the sediment loads that different species of sponges could tolerate (Grant *et al.*, 2019). Such studies are always area-specific due to differences in sediment particle size, oceanographic conditions and the tolerances of different VME indicator species and there are few examples of where they have been used to recommend buffer zones, possibly due to the cost of such work and the need to undertake separate studies for specific applications.

Application of the ICES Approach to Buffer Zones to Closed Areas in the NAFO Regulatory Area

The closed areas currently in place to protect coral and sponge in the NRA (NAFO, 2021) were created in joint meetings of managers and scientists (NAFO WGEAFFM) around significant trawl catches and did not consider the VME polygons, some of which were not known at the time the closures were put in place. Here, we have applied a modified version of the ICES approach to creating buffer zones to the NAFO closed areas to explore whether that method could be used by NAFO to provide additional protection to the VMEs, given that most of the closed areas are inside the VME polygons and leave VME which could be subject to SAI of fishing. This takes the concepts developed by ICES and applies them to the closed areas (hence the modification). ICES would apply the buffers to individual points or records (Figure 7.16) but have combined records into C-squares where they have used buffers as well (ICES Advice, 2020). Here we explore what the approach would look like if applied to the closed areas, using a portion of the Flemish Cap to illustrate our results.

To determine the buffer around the closed area to address **accuracy of the VME location** (ICES, 2013), we used the mean depth of the closure to determine if it was greater or less than 500 m. In all cases the mean depth of each of the closed areas was > 500 m (range 627 to 1 776 m) and so a buffer zone of approximately 2 times the local depth was applied. This is illustrated by the red buffer line in Figure 7.17.

To consider the position of fishing vessel gear on the seabed relative to the position of the vessel on the surface (**fishing vessel positional accuracy**) an additional buffer was placed outside of the red buffer zone (shown in green if Figure 7.17). The average depth of the closure was again used to estimate the wire out and from this value, the distance between the vessel and the towed gear (*i.e.*, the buffer zone) was calculated using Pythagorus' theorem:

$$b = \sqrt{c^2 - a^2}$$

Where a is the average depth of the closure, c is the warp out distance and b is the width of the buffer zone. In this example c was 2 x a.

The final step was to join any buffers that were within 3.5 nm of one another. In Figure 7.17 this occurred between closed areas 9 and 8. The buffer edges most proximate to one another were connected (dashed lines) using the red buffer in this example but could easily be applied to the green buffer to get a similar combined area.

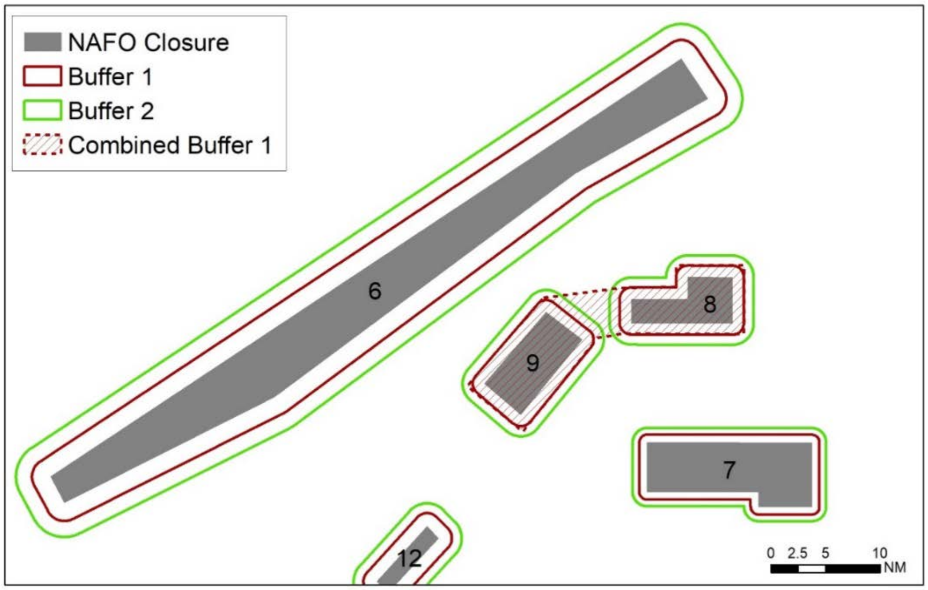

Figure 7.17. Example of NAFO closed areas with buffer zones applied. Buffer zone 1 incorporates VME positional accuracy while Buffer zone 2 adds extra width to ensure commercial bottom trawling does not encroach on the VMEs.

In Figure 7.18 we have overlain the significant concentrations and VME polygons for the sponges and sea pens associated with these closed areas. Note that the Area 6 (sponge) and Area 9 (sea pen) closed areas are within 3.5 nm of one another if the full ICES buffers are applied (green edge to green edge) and so could be combined. Adding buffer zones to the current closed areas would protect a greater proportion of the VME polygons and would seem to be particularly important for closed area boundaries inside the VME polygons.

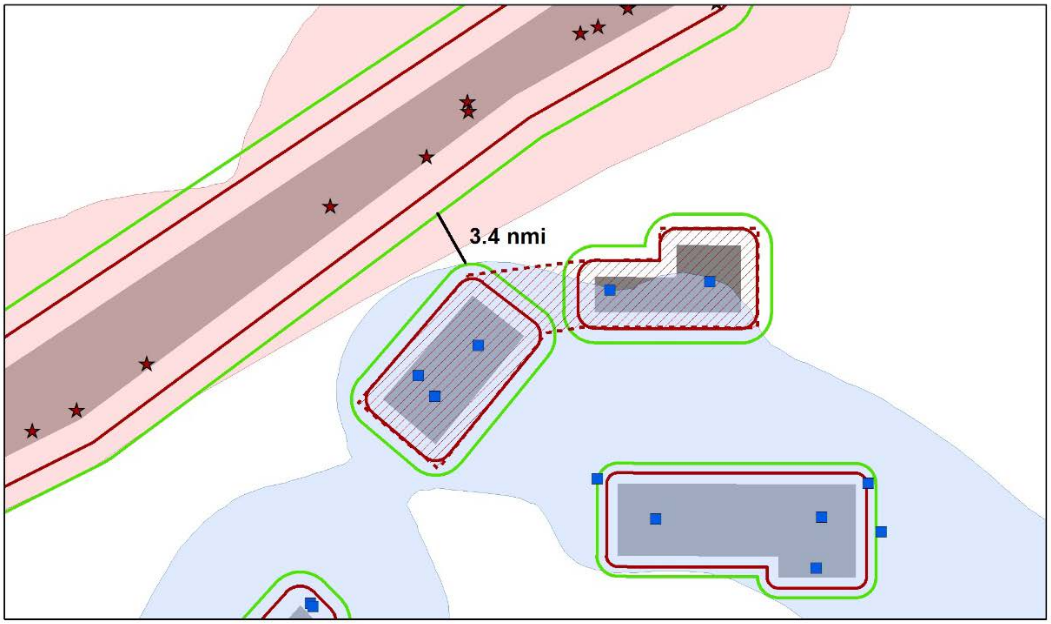

Figure 7.18. Example of NAFO closed areas with buffer zones applied. Buffer zone 1 incorporates VME positional accuracy while Buffer zone 2 adds extra width to ensure commercial bottom trawling does not encroach on the VMEs. VME polygons for sea pens (blue) and sponges (red) are shown in relation to the significant catches within the closed areas and vicinity.

vi) VME Closure Connectivity Index

WG-ESA has previously defined connectivity in the context of their work as: "physical links between two or more areas; an area is considered to have redundancy when two or more other areas connect to it. These properties relate to the ability of populations to persist." (NAFO, 2020).

In support of the 2020 NAFO review of the closed areas to protect Vulnerable Marine Ecosystems (VMEs) in the NAFO Regulatory Area (NRA), connectivity among the areas closed to protect Vulnerable Marine Ecosystems, and including Area 14 which was reopened to fishing in 2019, was assessed using Ocean Parcels, an interface to perform 3-D passive particle tracking simulations using output from an ocean circulation model, BNAM (NAFO, 2020). Connectivity is an important property for evaluating the effectiveness of the closures, and especially so for the benthic invertebrates under protection, all of which are sessile as adults and rely on larval transport for dispersal and persistence. At the 2019 meeting of WG-ESA, connectivity was evaluated among areas closed to protect large-sized sponges, large gorgonian corals and sea pens (NAFO, 2020). Overall, connectivity was generally low between closed areas, with downstream interdependence and limited redundancy. For each receiving area the percentage of the total number of particles released (from all source areas) were presented and were generally small (< 10%). The exception was the connectivity between Areas 5 and 4 on the eastern and southeastern slopes of Flemish Cap which had a relatively high degree of connectivity with ~ 20% of particles connecting at all depths simulated. Those areas connect populations of large gorgonian corals and sponges. The results of that modeling work along with the proportion of VME biomass protected were used to assess the protection status of VMEs (Tables 11.3 and 12.2 in NAFO, 2020). A simple classification scheme was used based on common English classes with both connectivity and redundancy considered to be 'Good' or 'Limited'.

The outcomes presented in the 2019 WG-ESA report (NAFO, 2020) have since been published in the primary literature (Wang *et al.*, 2020). Through the course of the review process the forward-tracking models were rerun with a shorter time step (20 min instead of 60 min) and backward-tracking models were added. Both resulted in small changes to the number of particle connections and retentions. In the previous analysis (NAFO, 2020), 17 connections between pairs of closed areas were recorded from the areas closed to protect sponges over all three release depths in forward-tracking models; in the Wang *et al.* (2020) there were 18 connections recorded in each of the forward- and backward-tracking models. All connections between closed areas pairs were the same between the publications, except for the addition of a connection between Area 5 to Area 3 in the summer releases from 1 245 m in the forward-tracking model of Wang *et al.* (2020). In terms of retention in the closed areas, both publications identified retention in Areas 2, 3, 4, 5 and 6, while in the newer analyses, Area 1 was added. A similar result was seen with the areas closed to protect sea pens where 32 connections between closed area pairs over all release depths were found in the previous analyses (NAFO, 2020), while 33 connections were recorded for the forward-tracking models, and 34 connections for the backward-tracking models. All 32 connections recorded previously (NAFO, 2020) were also found in the Wang *et al.* (2020) analyses, with four new connections added: Area 12 connecting to Area 9 (forward-tracking, 643 m, two (2) week duration, winter release), and Area 14 connecting to Areas 7, 12 and 9. These last connections involving Area 14 were only observed at the shallowest release depth (643 m) and under the longest duration (three (3) months). Retention observed in Areas 2, 7, 8, 9, 10 and 14 previously (NAFO, 2020) was also recorded in Wang *et al.* (2020) with the addition of Area 11. For the large gorgonian corals all analyses showed identical connections between closed area pairs, except one new connection was made between Area 4 and Area 5 at 643 m depth and three (3) month duration in the back-tracking model. The forward-tracking models in both publications showed the same results for retention (Areas 2, 4, 13), while the backward-tracking model (Wang *et al.*, 2020) added Area 5.

In the model runs, particles were released at different seasons to reflect what is known of the spawning times of the resident species, and for different lengths of time, reflecting what is known of the larval duration. The combined results of the forward- and backward-tracking models of Wang *et al.* (2020) are summarized here (Table 7.6). As noted previously, the current velocities create down-stream interdependence among closed areas and allow redundancy to develop in some of the areas of the network. Most areas also show retention although the percentage of particles retained is often low and reaches a maximum of 57% in Area 2, the largest closed area (Table 7.6, Figure 7.19). Source populations for sponges in the upstream closure (Area 6) are likely to come from adjacent waters of the Canadian continental shelf. Potential sources for sponge larvae drifting into Area 6 were identified as coming from the Northeast Newfoundland Slope Closure, a 55 353 km^2 Canadian marine refuge put in place to protect corals and sponges on the continental slope from all bottom contact fishing activities. This Canadian marine refuge may support the sponge populations in the high-seas NAFO area of Flemish Cap.

Table 7.6. Connectivity characteristics for each of the areas closed to protect coral and sponges in the NRA. Details of the connections can be found in Wang *et al.* (2020) and include results from 3D forward- and backward-tracking biophysical models using yearly and seasonally averaged oceanographic models. Note that the strength of the connections are not considered here and not all connections are likely to be equally effective. The range over all depth/duration/season models of percent particle retention is provided separately for the forward- (Fwd) and backward- (Bkd) tracking models. Shaded rows indicate the sea pen closed area network.

Closed Area	Conservation Target	Retention (Range of % of Released Particles)	Redundancy	Connectivity to other areas (Receiving Areas)	Connectivity from other areas (Source Areas)
Area 1	Sponge	Fwd (0-0.9%)	No	No	Area 2
Area 2	Sponge	Fwd (7.9-16.0%) Bwd (37.5-57.4%)	Yes	Area 1	Areas 3, 4, 5
Area 2	Sea Pens	Fwd (0.02-28.3%) Bwd (0.02-21.8%)	Yes	No	Areas 7, 8, 9, 10, 11, 12, 14
Area 2	Large Gorgonian Coral	Fwd (0.03-15.1%) Bwd (0.01-57.6%)	Yes	No	Areas 4, 5, 13
Area 3	Sponge	Fwd (0-0.9%) Bwd (0-0.1%)	Yes	Area 2	Areas 4, 5
Area 4	Sponge	Fwd (0-0.9%) Bwd (0.3-21.9%)	Yes	Area 2, 3, 5	Areas 5, 6
Area 4	Large Gorgonian Coral	Fwd (0-2.1%) Bwd (0-20.4%)	No	Areas 2, 5, 13	Area 5
Area 5	Sponge	Fwd (0-0.3%) Bwd (0-1.7%)	Yes	Areas 2, 3, 4	Areas 4, 6
Area 5	Large Gorgonian Coral	Bwd (0-1.7%)	No	Areas 2, 4, 13	Area 4
Area 6	Sponge	Bwd (0-1.6%)	No	Areas 4, 5	No (Canadian waters)
Area 7	Sea Pens	Fwd (0-10.7%) Bwd (0-8.4%)	Yes	Areas 2, 8, 9, 10, 11, 12, 14	Areas 8, 9, 14
Area 8	Sea Pens	Fwd (0-3.3%) Bwd (0-2.4%)	Yes	Areas 2, 7, 9, 10, 11, 12, 14	Areas 7, 9, 12, 14
Area 9	Sea Pens	Fwd (0-4.3%) Bwd (0-20%)	Yes	Areas 2, 7, 8, 10, 11, 12, 14	Areas 7, 8, 12, 14
Area 10	Sea Pens	Fwd (0-0.9%) Bwd (0-0.5%)	Yes	Areas 2, 11	Areas 7, 8, 9, 12, 14
Area 11	Sea Pens	Fwd (0-1.4%)	Yes	Area 2	Areas 7, 8, 9, 10, 12, 14
Area 12	Sea Pens	No	Yes	Areas 2, 8, 9, 10, 11	Areas 7, 8, 9, 14
Area 13	Large Gorgonian Coral	Fwd (0-2.4%) Bwd (0-0.6%)	Yes	Area 2	Areas 4, 5
Area 14	Sea Pens	Fwd (0-10.8%) Bwd (0-12.8%)	Yes	Areas 2, 7, 8, 9, 10, 11, 12	Areas 7, 8, 9

vii) Proposed Rating Scheme for Consideration of Management Actions

Following the approach applied in 2019, we created retention and binary (yes/no) connectivity and redundancy classifications for each of the closed areas examined (3O has not been evaluated), according to their conservation target. Applying a binary connectivity matrix metric is less conservative than the approach applied in 2019 because this does not consider the strength of the connection and highlights positive outcomes. However, the updated individual depth/duration summaries can be found in Wang *et al.* (2020). Table 7.6 provides the results from that classification and the results are shown graphically in Figure 7.19. All areas except Area 12, closed to protect sea pens, have potential for larval retention within their boundaries. However, the proportion of particles retained is highly variable (Table 7.6) with sponges in Area 1 having a very low proportion of particles retained (< 1%) while sponges and large gorgonian corals in the larger Area 2 may retain ~57% of particles. Many areas have some degree of redundancy except for Areas 6 and 1, closed to protect sponges, and positioned at the upstream and downstream ends of the network, and Areas 4 and 5 closed to protect large gorgonian corals. This is illustrated in Figure 7.19, where it can be seen that the sea pen network, particularly among Areas 7, 8, 9 and 14 is highly interconnected, while the sponges have a strong downstream interconnectance, and the large gorgonian corals have low redundancy.

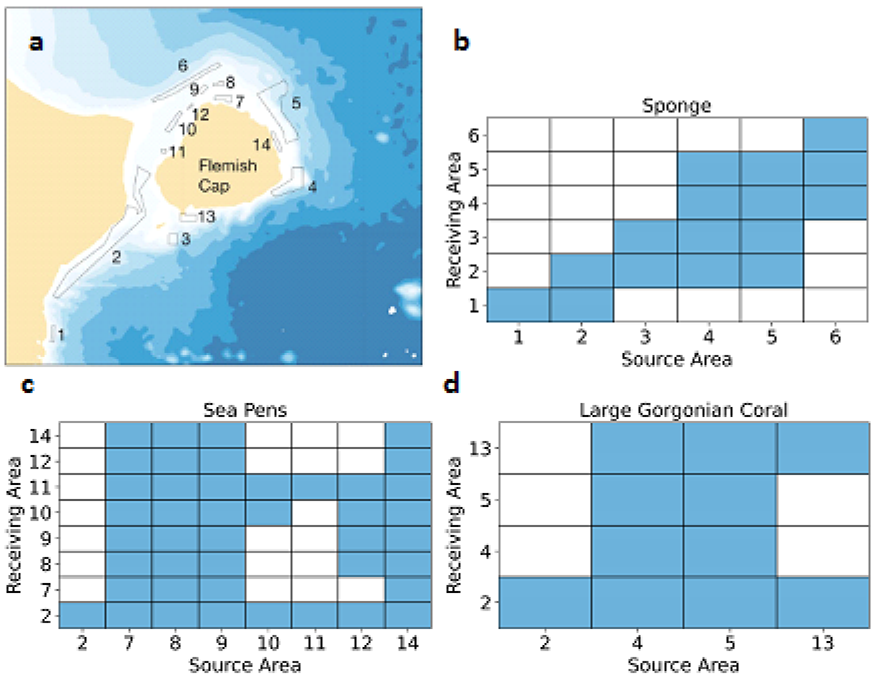

Figure 7.19. a) Closed Area numbers and location; b) Connectivity matrix for areas closed to protect large-sized sponges; c) Connectivity matrix for areas closed to protect sea pens; d) Connectivity matrix for areas closed to protect large gorgonian corals. The diagonals of the connectivity matrices indicate retention, other cells represent connectivity with more than one cell in each receiving area row indicating redundancy. Coloured cells indicate a positive connection.

The information in Table 7.6 was further condensed in Table 7.7 to classify the retention, redundancy and importance of the area as a larval source for other areas. An ordinal scale of Limited (< 1% maximum particle retention), Moderate (1-10%) and Strong (> 10%) was applied to the range of Retention values. An ordinal scale of No (0 or 1 connection), Moderate (2 or 3 connections) and Strong (4 or more connections) was applied to the Redundancy values. It is important to note that Area 12 is the only area where retention of sea pen larvae is unlikely. This closed area is the smallest of all the closures at only 35.1 km^2 and increasing its size would facilitate retention. The next largest sea pen closure is Area 11 which is 60.5 km^2 and which does have Moderate retention. Areas 1, 3 and 10 are the only areas with 'Limited' retention (Table 7.7). Redundancy and potential as a larval source for other closed areas provide more scope for ranking as there is more range in their combined status.

Table 7.7. Connectivity characteristics for each of the areas closed to protect coral and sponges in the NRA. Retention, Redundancy and Importance of the Area as a larval source are classed on an ordinal scale. Shaded rows indicate the sea pen closed area network.

Closed Area	**Conservation Target**	**Retention**	**Retention** Limited = < 1%; Moderate = 1-10%; Strong = > 10%	**Redundancy**	**Redundancy** No = no areas or 1 area; Moderate = 2-3 areas; Strong = 4+ areas	**Importance as a Larval Source for other Closed Areas** Limited = 1 area; Moderate = 2-3 areas; Strong 4+ areas
Area 1	Sponge	Yes	Limited	No	No	No
Area 2	Sponge	Yes	Strong	Yes	Moderate	Limited
Area 2	Sea Pens	Yes	Strong	Yes	Strong	No
Area 2	Large Gorgonian Coral	Yes	Strong	Yes	Moderate	No
Area 3	Sponge	Yes	Limited	Yes	Moderate	Limited
Area 4	Sponge	Yes	Strong	Yes	Moderate	Moderate
Area 4	Large Gorgonian Coral	Yes	Strong	No	No	Moderate
Area 5	Sponge	Yes	Moderate	Yes	Moderate	Moderate
Area 5	Large Gorgonian Coral	Yes	Moderate	No	No	Moderate
Area 6	Sponge	Yes	Moderate	No	No (Canadian waters)	Moderate
Area 7	Sea Pens	Yes	Strong	Yes	Moderate	Strong
Area 8	Sea Pens	Yes	Moderate	Yes	Strong	Strong
Area 9	Sea Pens	Yes	Strong	Yes	Strong	Strong
Area 10	Sea Pens	Yes	Limited	Yes	Strong	Moderate
Area 11	Sea Pens	Yes	Moderate	Yes	Strong	Limited
Area 12	Sea Pens	No	None	Yes	Strong	Strong
Area 13	Large Gorgonian Coral	Yes	Moderate	Yes	Moderate	Limited
Area 14	Sea Pens	Yes	Strong	Yes	Moderate	Strong

The existence of source and sink populations has implications for species conservation and MPA network design (Hansen, 2011). Sink populations depend upon immigration from other populations (sources) and may not persist otherwise (Dias, 1996). Larval retention in sink populations becomes very important to their persistence at least in the short-term, although such populations are susceptible to negative genetic consequences over generations (reduced fitness, inbreeding etc.). Source-sink dynamics in sessile benthic invertebrate species involves demographic processes governing recruitment and mortality, connectivity factors including physical transport mechanisms and larval dispersal behavior, and habitat heterogeneity in both quality and physical properties, across different spatial and temporal scales. Populations may become sinks as a result of patterns in ocean currents of the region, or because habitat quality is poor and individuals have low reproductive capacity as a consequence. It is important to identify source populations for conservation or management because they serve to maintain the broader distribution of the species. Preserving only sink habitats could lead to population extinction. Regional productivity in linked source and sink populations may be higher than in either alone, due to the subsidies to sinks from sources.

In the case of the benthic VME Indicators in the NRA it increasingly appears that physical transport plays a dominant role in population connectivity, given the current velocities at depth and the topography of the region (*i.e.*, passive density independent asymmetric dispersal, Dias (1996)). Our connectivity models allow us to infer whether each of the closed areas is a source or sink in the closed area network, for each of the VME Indicator groups. Areas that ranked 'No' or 'Limited' connectivity to other closed areas are considered 'Sink' areas, while areas with 'Moderate' or 'Strong' connectivity are considered 'Source' areas. Combinations present are shown in Table 7.8.

The lowest priority for management action is for 'Sink' areas that have 'Moderate' to 'Strong' Redundancy on the basis that such areas likely receive larvae from other closed areas to retain their local populations. Our evaluation of particle retention further allows for the sink areas to be prioritized for management action (sink areas with no or limited retention requiring greater management support (through increase in the size of the protected area)) to mitigate against local extinction. Sinks with moderate to strong retention have a less urgent need for management action.

Equally, 'Strong' Redundancy in 'Source' areas indicate that the area is well placed and functioning well in the network. Increase in size of the areas (or placement of new areas to bridge large connection distances) could be warranted for both 'Source' and 'Sink' areas when Redundancy is zero or 'Limited', especially if the area is shown to retain larvae. Increase in area will compensate for the lack of redundancy to some extent, if Retention can be increased to 'Moderate' to 'Strong'. 'Source' areas with 'Moderate' to 'Strong' Redundancy and similar connectivity to other areas warrant size increase to maximize their important functioning in the network. We note that the closed areas were selected based on the records of high biomass for each VME Indicator, and that evaluation of connectivity among them was not a factor in their designation. The distributions of each VME Indicator are well documented in the NRA and protective networks could be enhanced by the strategic introduction of new closures around source populations.

Table 7.8. Combinations of redundancy and importance of as a larval source present based on connectivity analyses of the NAFO Closed Areas with management recommendations *considering only Connectivity*.

Redundancy	Importance as a Larval Source for other Closed Areas	Source/Sink Area	Recommendation	Closed Areas Meeting Criteria
No (Canadian waters)	Moderate	Source	Consider Size Increase especially if Retention is Limited	Area 6 (sponge)
No	No	Sink	Consider Size Increase especially if Retention is Limited	Area 1 (sponge)
No	Moderate	Source	Consider Size Increase especially if Retention is Limited	Area 4 (LGC); Area 5 (LGC);
Moderate	No	Sink	No action	Area 2 (LGC)
Moderate	Limited	Sink	No action	Area 2 (sponge); Area 3 (sponge); Area 13 (LGC)
Moderate	Moderate	Source	Consider Size Increase	Area 4 (sponge); Area 5 (sponge);
Moderate	Strong	Source	Consider Size Increase	Area 7 (sea pen); Area 14 (sea pen)
Strong	No	Sink	No action	Area 2 (sea pen)
Strong	Limited	Sink	No action	Area 11 (sea pen)
Strong	Moderate	Source	Consider Size Increase	Area 10 (sea pen)
Strong	Strong	Source	Consider Size Increase	Area 8 (sea pen); Area 9 (sea pen); Area 12 (sea pen)

Future Work

The connectivity work updated here can be used in future to fine tune the fragmentation indices between Closed Area pairs (Section 7.b)vi). The work to date has been performed using the Closed Areas to seed the particles, but future work could undertake the same analyses applied to each of the VME polygons (Kenchington *et al.*, 2019) to complement work on the fragmentation indices and to identify source and sink VMEs for management action prioritization and a more comprehensive review of the closed area networks operating in the NRA.

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Classification of fisheries distribution effort

i) Description of the fisheries in the NRA

Within the NAFO Regulatory Area (NRA) there are the following main fishery categories: groundfish (GRO - primarily in Divs. 3KLMNO), shrimp (PRA - primarily in Div. 3LM), pelagic redfish (REB - primarily in Div. 1F and 2J) and alfonsino (ALF - Division 6G). Occasionally, a short-finned squid fishery takes place mainly in Div. 3O. Fisheries are conducted mainly with trawl gear, 92% of the total effort, and to a lesser extent with long lines, 8% of the total effort. It was used the adopted NCEM definition of a directed fishery (NCEM Art. 5.2) to provide a basis to classify various fisheries.

To understand the extent of fishing activities within NRA, a characterization of the different fisheries and their footprint for a four (4) year period (2016 to 2019) was conducted. This characterization was done on the basis of two (2) data sources: Haul by haul logbook information and Vessel Monitoring System (VMS) data. The method developed for this study has been described by Sacau *et al., (2020)*. The method uses the logboook haul-by-haul information to assign the VMS pings as “fishing” or “non-fishing” based on whether or not they fall within fishing time intervals reported in the haul-by-haul logbook information. This method also allows the different pings to be assigned to the different fisheries based on the catches collected in the logbooks. The results indicate that logbook data and VMS are complementary and the coupling of both datasets is a powerful methodology for describing the spatial distribution of fishing activity.

Despite the problems with the data and the fact that the information available in the logbooks is not the most adequate to describe the effort of longliners, WG-ESA considers that the merging VMS with logbook method can describe reasonably well the footprint of the longliners fisheries carried out in NAFO. However, WG-ESA maintains the recommendation to collect and compile additional information in the logbooks to better describe and represent a more precise fishing bottom longline footprint.

Considering their target species/stocks identified in the NCEM Annex I.A or I.B, main area of operation and gear, a total of 21 fisheries have been initially identified. Twelve of the 21 fisheries have been operational in the period studied (2016-2019) and were taken into account for the Reassessment of Bottom Fishing Activities (Table 7.9). The analyses also include small scale fisheries not managed by NAFO targeting Atlantic halibut and Silver hake in the NRA for which NAFO does not set a TAC. Other bottom fisheries not managed under the NAFO convention (*e.g.*, snow crab, surf clam) were not included in the SAI analysis. WG-ESA did review the spatial information available on their fishing footprint and such fisheries were not considered an important source of SAI as they did not overlap with VMEs. In addition, the Redfish fisheries in Div. 1F, 2J and 3K, and the *Alfonsino* fisheries on seamounts in Div. 6G were not described herein as they use midwater trawls and not the bottom-contact fishing gears for which the UNGA resolutions call for assessments.

The description of demersal fisheries (footprint, fleet characteristics, etc), based on the logbook and VMS data for the period 2016-2019, is illustrated in Section 7.c)iii.

Table 7.9. Operational fisheries identified in the NRA. The fisheries for consideration in the process of developing the Reassessment of Bottom Fishing Activities based on the 2016-2019 data are highlighted in grey.

Fishery	Target Species	Main Area of Operation	Gear
Greenland Halibut Fishery	Reinhardtius hippoglossoides	NAFO Divs 3LMNO	Bottom otter trawl
Northern shortfin squid Fishery	Illex illecebrosus	NAFO SA 2+3	Bottom otter trawl
Redfish Fisheries	Sebastes spp.	NAFO Div. 3M	Bottom otter trawl
	Sebastes spp.	NAFO Divs 3LNO	Bottom otter trawl
	Sebastes spp.	NAFO Divs 3O	Bottom otter trawl
	Sebastes spp.	NAFO Divs. 1F2G (moratorium 2016-2019)	Peleagic trawl
Cod Fisheries	Gadus morhua	NAFO Div. 3M	Bottom otter trawl
	Gadus morhua	NAFO Div. 3M	Longline
	Gadus morhua	NAFO Div. 3NO (moratorium 2016-2019)	Bottom otter trawl
	Gadus morhua	NAFO Div. 3L (moratorium 2016-2019)	Bottom otter trawl
Skate Fishery	Amblyraja radiata	NAFO Divs. 3LNO	Bottom otter trawl
Yellowtail flounder Fishery	Pleuronectes ferruginea	NAFO Div. 3LNO	Bottom otter trawl
Witch flounder Fisheries	Glyptocephalus cynoglossus	NAFO Divs. 3NO	Bottom otter trawl
	Glyptocephalus cynoglossus	NAFO Div. 3L (moratorium 2016-2019)	Bottom otter trawl
American plaice Fisheries	Hippoglossoides platessoides	NAFO Divs. 3LNO (moratorium 2016-2019)	Bottom otter trawl
	Hippoglossoides platessoides	NAFO Div. 3M (moratorium 2016-2019)	Bottom otter trawl
Shrimp Fisheries	Pandalus spp.	NAFO Div. 3M (moratorium 2016-2019)	Bottom otter trawl
	Pandalus spp.	NAFO Div. 3L (moratorium 2016-2019)	Bottom otter trawl
White hake Fisheries	Urophycis tenuis	NAFO Divs. 3NO	Bottom otter trawl
	Urophycis tenuis	NAFO Divs. 3NO	Longline
Atlantic halibut Fisheries (not managed by NAFO)	Hippoglossus hippoglossus	NAFO Divs. 3NO	Bottom otter trawl
	Hippoglossus hippoglossus	NAFO Divs. 3NO	Longline
Silver hake Fishery (not managed by NAFO)	Merluccius bilinearis	NAFO Divs. 3NO	Bottom otter trawl
Splendid alfonsino Fishery	Beryx splendens	NAFO Div. 6G	Pelagic trawl

Reference:

Sacau, M., Durán-Muñoz, P., Garrido, I and Baldó, F. Improvements in the methodology to study the bottom fishing footprint in the NRA using VMS and logbook data. NAFO SCR Doc. 20/069. Serial No. N7145

ii) Integrating VMS and Logbook data

During the 10th NAFO Working Group on Ecosystem Science and Assessment (WG-ESA) meeting the "*coupling VMS with Logbook data*" the original methodology (NAFO, 2017) needed to link those elements was described and presented in order to characterize the distribution and intensity of fishing effort from 2016 onwards. It was possible to apply this methodology from 2016 onward, as a result of a new logbook data format implemented after 2015, which allowed improved interpretation of the Logbook data by including fishing timestamps, geographic coordinates for gear deployment and retrieval, as well as the catch and discard weight for each species caught.

In 2020, some technical problems with the original methodology (NAFO, 2017) were identified via additional studies on fishing effort (Garrido *et al.*, 2020). This Section describes the original methodology and its strengths and presents some improvements made on it to tackle several issues detected in the original methodology. A detailed description of the improved methodology is given by Sacau *et al*. (2020).

The distribution and intensity of fishing effort during the period 2016-2019 in the NRA were estimated based on two data sources: a) Vessel Monitoring System (VMS) and b) logbook information data.

Vessel Monitoring System (VMS)

The NAFO Vessel Monitoring System (VMS) is a satellite-based monitoring system that provides data on the location, heading and speed of licensed fishing vessels. The transmission of such data occurs approximately every hour, called a "*ping*", providing high resolution positions recorded at higher frequencies when compared to logbook reporting.

VMS data used in this work were obtained from NAFO Secretariat who has responsibility for collecting and maintaining VMS data from fishing vessels in the NRA. In addition to be an integral part of NAFO´s Monitoring, Control and Surveillance (MCS) scheme, the VMS data is also used for scientific purposes, *e.g.,* for the assessment of Significant Adverse Impacts (SAIs) on Vulnerable Marine Ecosystems (VMEs) and fish stock assessments.

VMS data includes the following information: NAFO Vessel Identification; Flag State; Radio (vessel call sign); UTC date and Time of the vessel position; vessel position by latitude and longitude; speed and heading (Annex II.E, NAFO, 2020).

Haul-by-haul catch data (logbook data)

Haul-by-haul catch data is logbook data collected during fishing vessel activities. Specifically, timestamps and geographic coordinates for gear deployment and retrieval are recorded, as well as the catch and discard weight for each species caught (Annex II.A, NAFO, 2020). This data format was implemented in 2016, and is an improvement over 2015 where the data were recorded only for the top three species by weight and did not include fishing time-stamps.

Haul-by-haul logbook data used for this work was also provided by NAFO Secretariat. It provides details for each vessel on catch and discard characteristics, date, type of gear used, and geographic position collected during fishing vessel activities. The collection of these data is the responsibility of the skipper of each vessel.

VMS/logbook data quality

A key step when studying the environmental impact of fishing activity is to assess the fishing footprint. There are two methodologies to study the fishing effort and footprint in the NAFO Regulatory Area (NRA). The first one uses a simple speed filter to select the Vessel Monitoring System (VMS) pings most likely to be associated with fishing activity. The second one filters the VMS pings that correspond with the haul fishing time interval registered by the skipper in the logbook.

Two analyses (Garrido *et al.*, 2020 and Sacau *et al.*, 2020) have focussed on the quality and coverage of VMS and logbooks data. According to Garrido *et al.*, (2020) there are a few problems, both in terms of quality and coverage of these data. The source of these problems is varied and is more related to submission problems and human errors in logbooks while in VMS they are usually to the result of technical problems. The problems with the submission of logbooks seem to have been declining gradually since 2016 and the present submission rates of fishing trips information is near to 100%.

VMS data transmission problems may have an effect in application of the VMS speed filter and in merging of the VMS and logbook data, because the missing pings are lost in both treatments. The logbook problems (missing trips and/or haul information) only affect the merging of the data used to analyse the overlap of NAFO Fisheries with VME. We also observed that after merging the two data sets, the effects of the misreporting become more pronounced when the coverage is not 100%. Garrido *et al*. (2020) found that when both data sets were merged, only around 60-70% of the total pings were taken into account based on the hauls observed by Spanish scientific observers on board.

The quality of the information, both in the VMS system and in the logbooks, should be of concern to NAFO. The improvement of the quality of these data is crucial for better studying the effort distribution and the tasks related to this effort (SAI, fisheries footprint, fishing overlap with VME, assessments, etc). WG-ESA recommends that the NAFO Secretariat carry out a study on the problems detected and propose measures to solve them.

"*Coupling VMS with Logbook*" methodology

Logbook data and VMS are complementary and the coupling of both datasets has already proven powerful for describing the spatial distribution of fishing activity at a much finer resolution (NAFO, 2017). Figure 7.20 illustrates the flowchart with the main steps involved in the procedure of linking VMS with logbook data. The entire framework is a modular structure where each step has been developed in open-source statistical computing environment R (R Code Team, 2020).

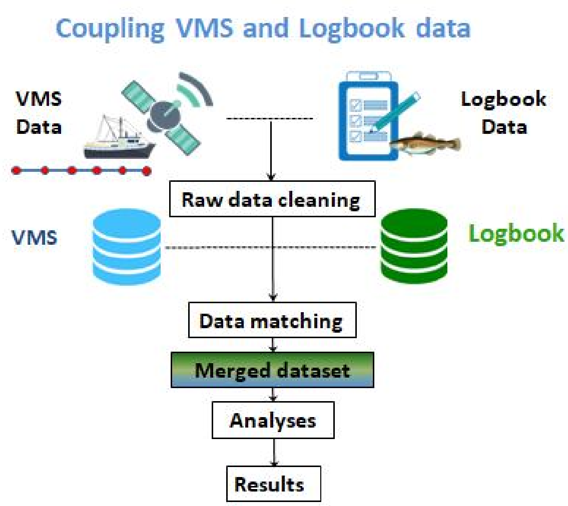

Figure 7.20. Flowchart with the main steps involved on the procedure of coupling VMS and logbook data.

The first important step is "*Raw Data Cleaning*". In many instances, both VMS and logbook data contain erroneous entries, namely: points with incomplete timestamps; wrong vessel positions; duplicated records; headings outside a compass range, etc. These errors should be removed or flagged.

Once the cleaning has been performed both datasets are ready for the "*Data Matching*" by using the NAFO Vessel ID and the Date as common fields between both databases. This step is particularly important as all subsequent analyses depend on the success of the linking. From the "*Merged dataset*" we can start to do the "*Analyses*" and get the final "*Results*".

Use of the haul-by-haul data permits VMS pings to be assigned as "*fishing*" or "*non-fishing*" based on whether or not they fall within fishing time intervals reported in the haul-by-haul catch data (match in time window, see Figure 7.21). That is, start and end of fishing timestamps from the logbooks are used to extract relevant VMS points which are then mapped in space to represent fishing effort. Because these VMS points are directly within the reported fishing times interval, they are considered to be associated with fishing activity.

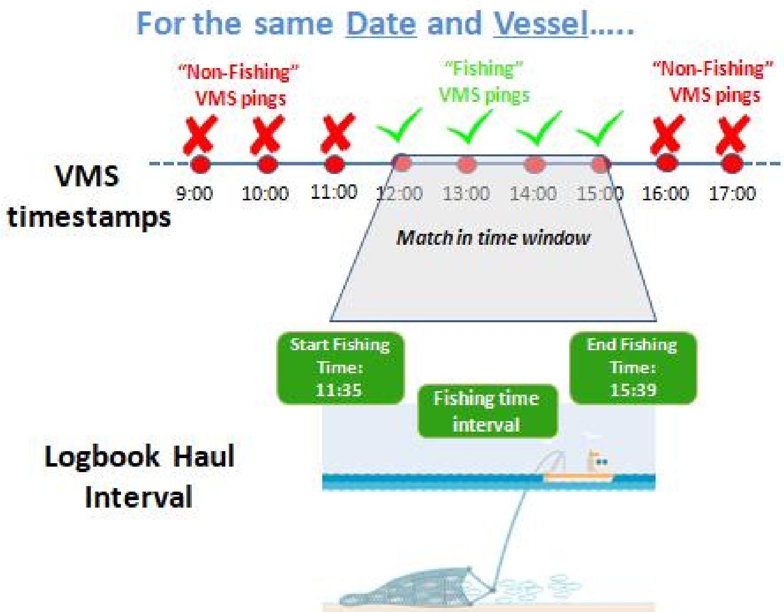

Figure 7.21. Match in time window procedure.

Through this analysis, fishing footprint layers were created for fisheries-specific and cumulative fishing effort using VMS data and new haul-by-haul catch data (logbook).

To create fishery-specific effort maps, VMS points were assigned to a fishery based on the species with the highest retained catch weight in the logbook during the corresponding logbook fishing time interval. This definition of fishery is based solely on the main species in the catch and in some cases, the main species may differ from the main species sought.

Filtered VMS points were assigned a "*ping-time*" interval to represent the duration of fishing. This value was calculated as the forward difference in time between VMS points. Typically, ping intervals were approximately one hour, so if the interval exceeded 2 hours, it was assigned to be 2 hours to avoid inflating effort within a cell. The last VMS point in a vessel's series was assigned the mean ping-time interval for that vessel. The VMS points were aggregated over a 0.05 x 0.05 degree grid and the ping-time intervals were summed to represent the hours fished in each cell. However, Garrido *et al*., 2020 showed that around 3% of the sets have under or overestimation pings problems and 25% of the received pings have frequencies different to one hour.

New methodology: Issues found in the "*coupling VMS with Logbook*" original method

Despite the fact that the "*coupling VMS with Logbook*" original methodology has been shown to improve the description of the spatial distribution of fishing activity at a much finer resolution, some problems were detected in some steps of the original methodology. The following improvements were implemented with the aim to tackle such problems:

Calculation of bottom longline footprint

Bottom trawl and bottom longline fishing gears can produce negative impacts on VMEs, but technical and operative characteristics of both gears are very different. Consequently, the parameters needed to describe their footprints and associated impacts are very different too. For this reason, trawl and longline cumulative fishing effort need to be calculated separately.

According to the discussions of the SC 2020 Annual Meeting, "*... in the case of longline fisheries, collection and compilation of additional information would be crucial to start the process of defining a more precise fishing bottom longline footprint...... since with the information that is currently available, it is not possible to obtain the real footprint for this fishery*".

Despite the problems with the data and the fact that the information available in the logbooks is not adequate to describe the effort of longliners and their SAI in the VME, WG-ESA considers that the merging VMS with logbook method can describe reasonably well the footprint of the longline fisheries carried out in NAFO. However, WG-ESA maintains the recommendation to collect and compile additional information in the logbooks to better describe and represent a more precise fishing bottom longline footprint.

Missing "Fishing VMS pings"

Garrido *et al*., 2020 found that there were many missing pings in the original methodology to "*couple VMS with Logbook*" (NAFO, 2017). This occurs because many hauls with start times on one day and finish times next day (*e.g.*, Haul 1; Start day: 2 January; Start time 23:45; End day: 3 January; End Time 04:00). In these cases, VMS pings from the second day of the same haul were not taken into account and therefore missed from the analysis. This is not unusual so, the new proposed methodology takes into account those missing VMS pings considering all "*fishing pings*" comprised between start and end of the haul, including when the dates for the same haul and vessel are not the same day. Solving this issue is really important as all subsequent analyses depend on the success of the linking with the selection of all the "*fishing pings*".

Bottom trawlers fishing speeds

It has been noted that with the original methodology there were many vessels with very high speeds. Changes in the methodology apply a speed filter to the trawl effort in order to remove those vessels with speeds equal or higher than 6 knots, as it is considered that those are non trawling fishing speeds. The new methodology considers that bottom trawlers are classified as "*fishing*" in the coupling VMS Logbook data at speed intervals lower than 6 knots. Other speeds should be classified as "*steaming*".

Conclusions

The new "*coupling VMS with Logbook*" methodology has been demonstrated to improve the identification of "*fishing VMS pings*" by taking into consideration missing pings that were not taken into account by the original methodology. This new methodology also considers the fact that the parameters needed to describe the footprints and associated impacts of trawlers and longliners are different and therefore, their corresponding "*fishing VMS pings*" must be considered separately when calculating the cumulative fishing effort.

Even though the new methodology has been found to be an improvement over the original application, thereby refining the spatial distribution of bottom fishing activity, many issues were raised in terms of quality of data. Therefore, misreporting and errors found in VMS and Logbook data should be further analysed (*e.g.,* through a previous quality control check process).

All this improvements will help to increase the quality of data (VMS and Logbook) that is being used, among other analysis, to better understand if and how fishing effort is changing over the years in the NAFO Regulatory Area.

Acknowledgements

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iii) Demersal fisheries

The demersal groundfish fisheries in the NRA in the period 2016-2019 were conducted in Divs. 3LMNO. The semipelagic fisheries of Redfish Divs. 1F2G and of Alfonsino Div. 6G are excluded from this analysis. Bottom fisheries not managed under the NAFO convention (Atlantic halibut and Silver hake), were included in the analysis. The demersal groundfish fisheries were separated into different components depending on the main fishing grounds and their target species/stocks identified in the NCEM Annex I.A or I.B and gear. These fisheries were carried out mainly with trawl gear, 92% of the total fishing effort in the NRA in the period 2016-2019, and to a lesser extent with long lines, 8% of the NRA total fishing effort. To characterize the different fisheries (catches, fleet characteristics, etc.), the data from the logbooks for the period 2016-2019 have been used. To make the different fisheries footprint maps, the new merging VMS and logbooks data method, explained in Section 7.c)ii of this report, was applied to the 2016-2019 data.

Divisions 3LMNO

There are two principal demersal trawl fisheries in the NRA that are conducted on widely distributed stocks in the NRA: Greenland halibut and Northern squid. Figure 7.22 shows the box plots of the depths where these fisheries are carried out.

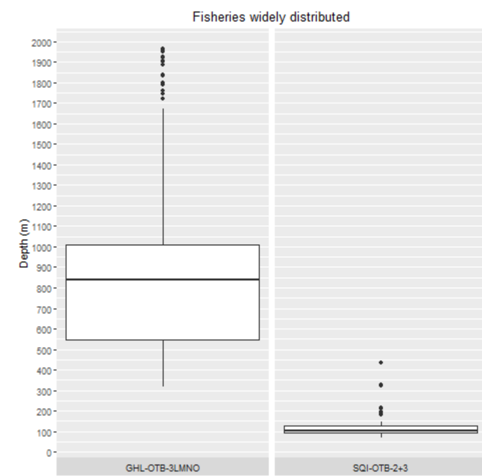


Figure 7.22. Depth box plot of the directed hauls to Greenland halibut (GHL) and Northern squid (SQI) in the NRA Divs. 3LMNO for the period 2016- 2019.

Greenland Halibut Trawl 3LMNO (GHL-OTB-3LMNO): This is one of the main fisheries currently conducted in the NRA. Figure 7.23 shows the fishery footprint of Greenland halibut in Divs. 3LMNO and Table 7.10 presents the main characteristics of this fishery. The fishery is carried out mainly at depths of 550-1 000 m in Divs. 3LMNO using demersal trawl gear with 130 mm cod-end mesh size. Records indicate that 19 vessels of different flag states participate each year and the effort of this fishery represents 33% of the total trawl effort in the NRA. The spatial footprint of this fishery is quite stable from year-to-year. Greenland halibut is the target species (94% of the total catches) and the main bycatch species is Roughhead grenadier (2%).

Table 7.10. Greenland halibut 3LMNO directed fishery characteristics.

Target species	**Division**	**Depth (m)**	**Trawl effort (%)**	**Logbook Catch Composition (2016-2019)**	
				Species	**Catch (%)**
Greenland halibut	3LMNO	550-1000	33.2%	Greenland halibut	93.8
				Roughhead grenadier	1.8
Vessels / year	**Gear**	**Mean power (kW)**	**Mean length (m)**	Others	4.4
19	Trawl (130 mm)	1653	67		

Greenland halibut (GHL)

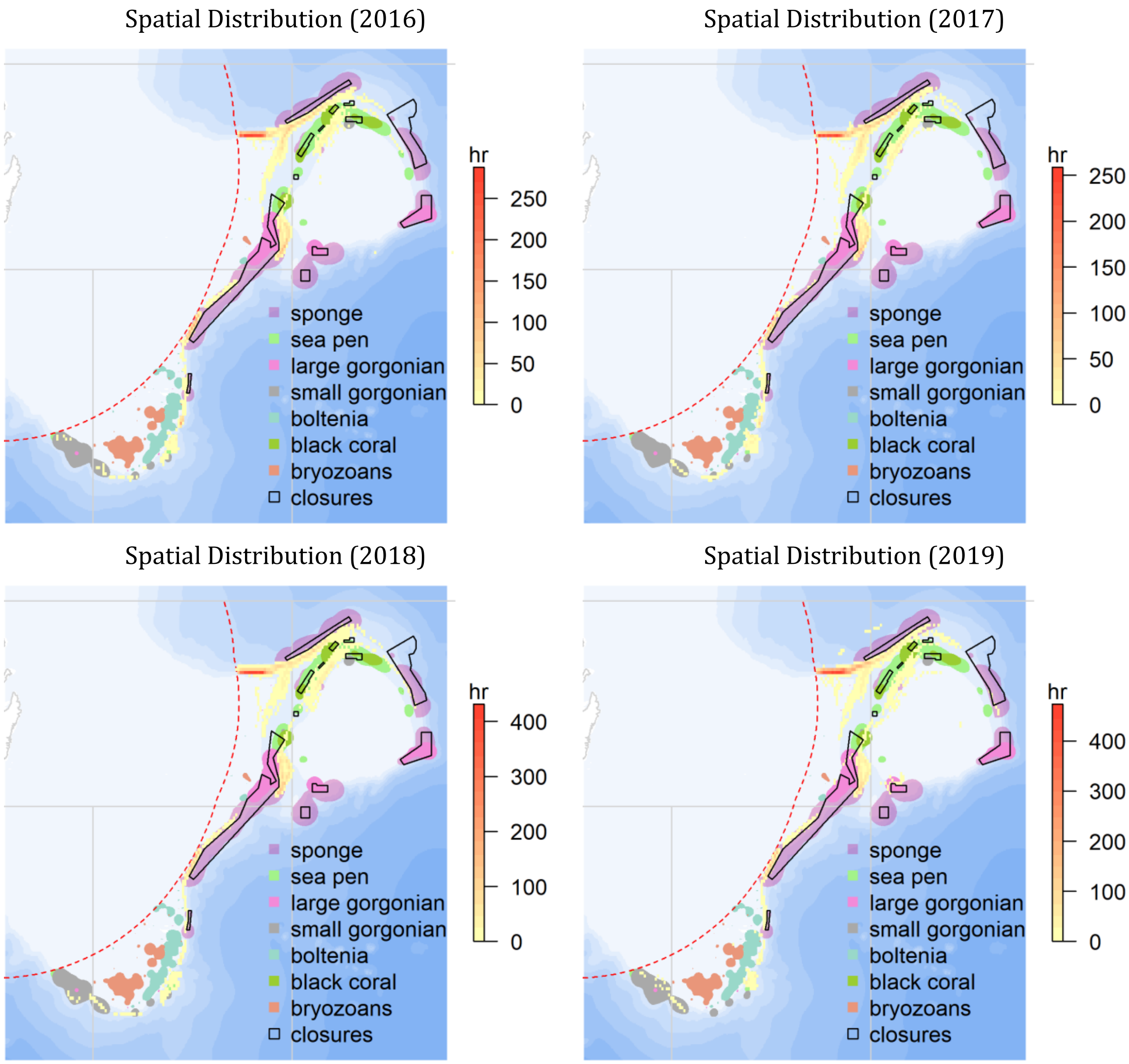


Figure 7.23. Greenland halibut Divs. 3LMNO fishery footprint together with the location of the VME polygons in the NRA, colour coded by taxon. Closed areas are indicated in black outline. Fishing activity (from yellow to red) is expressed in hours fished in each cell.

<u>Northern squid trawl 3LMNO (SQI-OTB-2+3)</u>: This fishery is carried out during the second half of the year sporadically, depending on the annual availability of the species in the NRA. Figure 7.24 shows the Northern squid Divs. 3LMNO fishery footprint and Table 7.11 presents the main characteristics of this fishery. In the period 2016-2019 there are only two years (2018 and 2019) in which a directed fishery for Northern squid occurred. The fishery is carried out mostly at depths of 90-150 m, manly in Div. 3NO, using demersal trawl gear with 60 mm cod-end mesh size. Records indicate that 4 vessels participate each year and the effort of this fishery represents 0.1% of the total trawl effort in the NRA. Northern shortfin squid is the target species (67% of the total catches) and the main bycatch species are Silver hake (19%), White hake (4%) and Skates (4%).

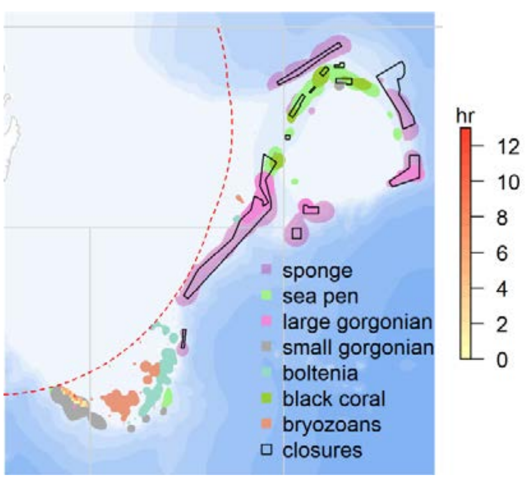
Table 7.11. Northern shortfin squid Subarea 2+3 directed fishery characteristics.

<table>
<tr><th>Target species</th><th>Division</th><th>Depth (m)</th><th>Trawl effort (%)</th><th colspan="2">Logbook Catch Composition (2016-2019)</th></tr>
<tr><td rowspan="3">Northern shortfin squid</td><td rowspan="3">3LMNO</td><td rowspan="3">90-150</td><td rowspan="3">0.1%</td><td>Species</td><td>Catch (%)</td></tr>
<tr><td>Northern squid</td><td>67.3</td></tr>
<tr><td>Silver hake</td><td>19.2</td></tr>
<tr><td rowspan="2">Vessels / year</td><td rowspan="2">Gear</td><td rowspan="2">Mean power (kW)</td><td rowspan="2">Mean length (m)</td><td>White hake</td><td>4.0</td></tr>
<tr><td>Skates</td><td>3.8</td></tr>
<tr><td rowspan="3">4</td><td rowspan="3">Trawl (60 mm)</td><td rowspan="3">1354</td><td rowspan="3">63</td><td>Redfish</td><td>2.3</td></tr>
<tr><td>Atlantic halibut</td><td>1.3</td></tr>
<tr><td>Others</td><td>2.1</td></tr>
</table>

Northern squid (SQI)

Spatial Distribution (2016) - Spatial Distribution (2018)

Spatial Distribution (2017) - Spatial Distribution (2019)



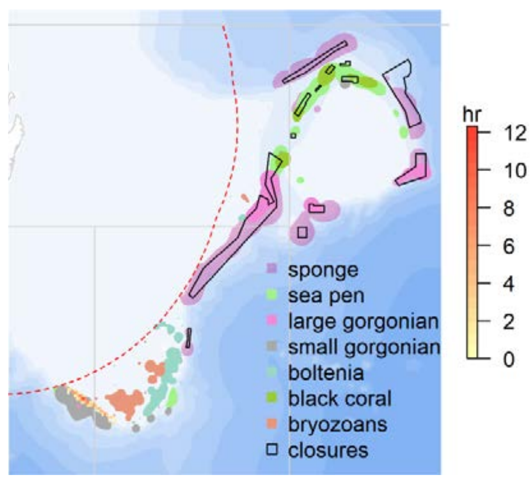


Figure 7.24. Northern squid fishery footprint together with the location of the VME polygons in the NRA, colour coded by taxon. Closed areas are indicated in black outline. Fishing activity (from yellow to red) is expressed in hours fished in each cell.

Division 3M

There are three different fisheries targeting cod and redfish in NAFO Div. 3M: One of them is targeting cod with trawls, the second is targeting cod with longlines and the last targeting redfish with trawls. Figure 7.25 shows the box plots of the depths where these fisheries are carried out.

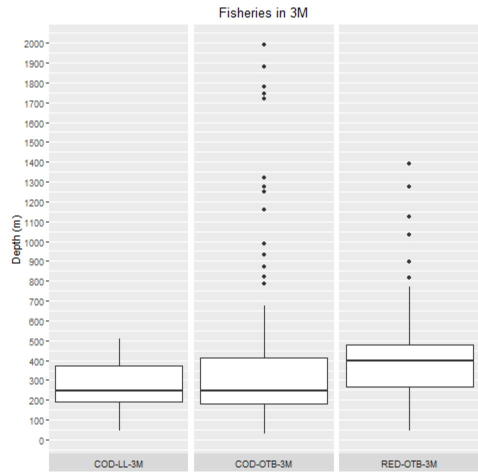


Figure 7.25. Depth box plot of the directed hauls to Cod and Redfish in the NRA Div. 3M by gear in the period 2016- 2019.

Cod Trawl 3M (COD-OTB-3M): Figure 7.26 shows the Cod trawl Div. 3M fishery footprint and Table 7.12 presents the main characteristics of this fishery. The fishery is conducted mainly in areas with depths ranging from 150 to 450 m in the southeastern part of the Flemish Cap bank (Div. 3M) using demersal trawl gear with 130 mm cod-end mesh size. Records indicate that 15 vessels of different flag states participate each year and the effort of this fishery represents 16% of the total trawl effort in the NRA. Cod is the target species (94% of the total catches) and the main bycatch species are Redfish (4%) and American plaice (1%).

Table 7.12. Cod 3M directed trawl fishery characteristics.

Target species	**Division**	**Depth (m)**	**Trawl effort (%)**	**Logbook Catch Composition (2016-2019)**	
				Species	**Catch (%)**
Cod	3M	150-450	15.8%	Cod	93.7
				Redfish	3.7
Vessels / year	**Gear**	**Mean power (kW)**	**Mean length (m)**	American plaice	1.2
				Others	1.4
15	Trawl (130 mm)	1868	64		

Cod (COD-OTB)

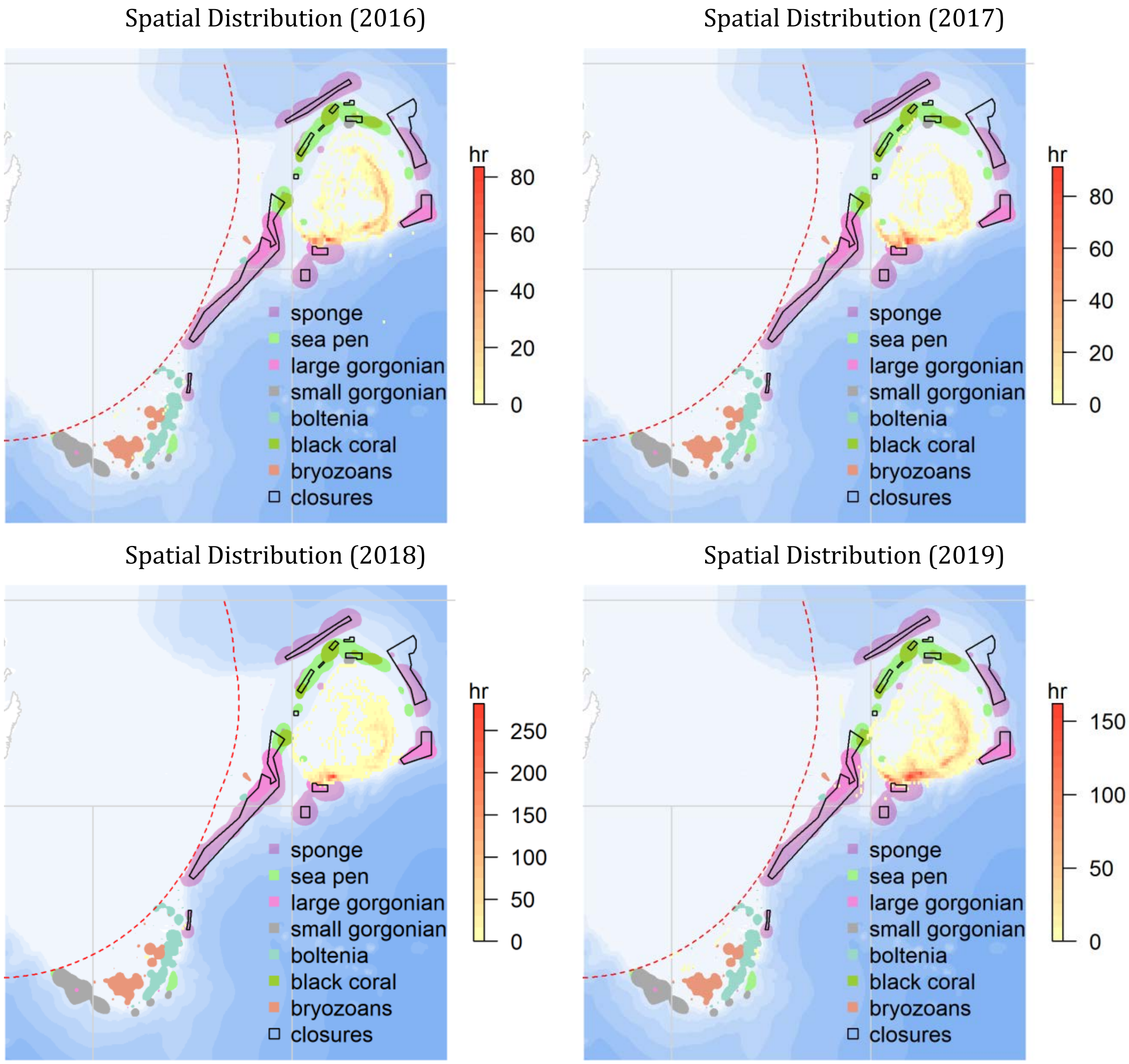


Figure 7.26. Cod 3M OTB fishery footprint together with the location of the VME polygons in the NRA, colour coded by taxon. Closed areas are indicated in black outline. Fishing activity (from yellow to red) is expressed in hours fished in each cell.

Cod longline 3M (COD-LL-3M): Figure 7.27 shows the Cod longline Div. 3M fishery footprint and Table 7.13 presents the main characteristics of this fishery. The fishery is mainly conducted over areas with depths from 200-400 m in the central and south part of the Flemish Cap bank (Div. 3M) with demersal longline gear. The footprint of this fishery is different from that observed in the cod 3M trawl fishery. Records indicate that 8 vessels of different flag states participate each year and the effort of this fishery represents 71% of the total longline effort in the NRA. Cod is the target species (99% of the total catches). Bycatch from this fishery is around 1% of the total catches. Although it is known that in 2017 there was a longline fishery directed to cod in Div. 3M, although this information was not recorded in logbooks. Therefore, the figure of the footprint of this fishery is not available for 2017.

Table 7.13. Cod 3M directed longline fishery characteristics.

Target species	**Division**	**Depth (m)**	**Longline effort (%)**	**Logbook Catch Composition (2016-2019)**	
				Species	**Catch (%)**
Cod	3M	200-400	70.9%	Cod	99.1
				Others	0.1
Vessels / year	**Gear**	**Mean power (kW)**	**Mean length (m)**		
8	Longline	960	42		

Cod (COD-LL)

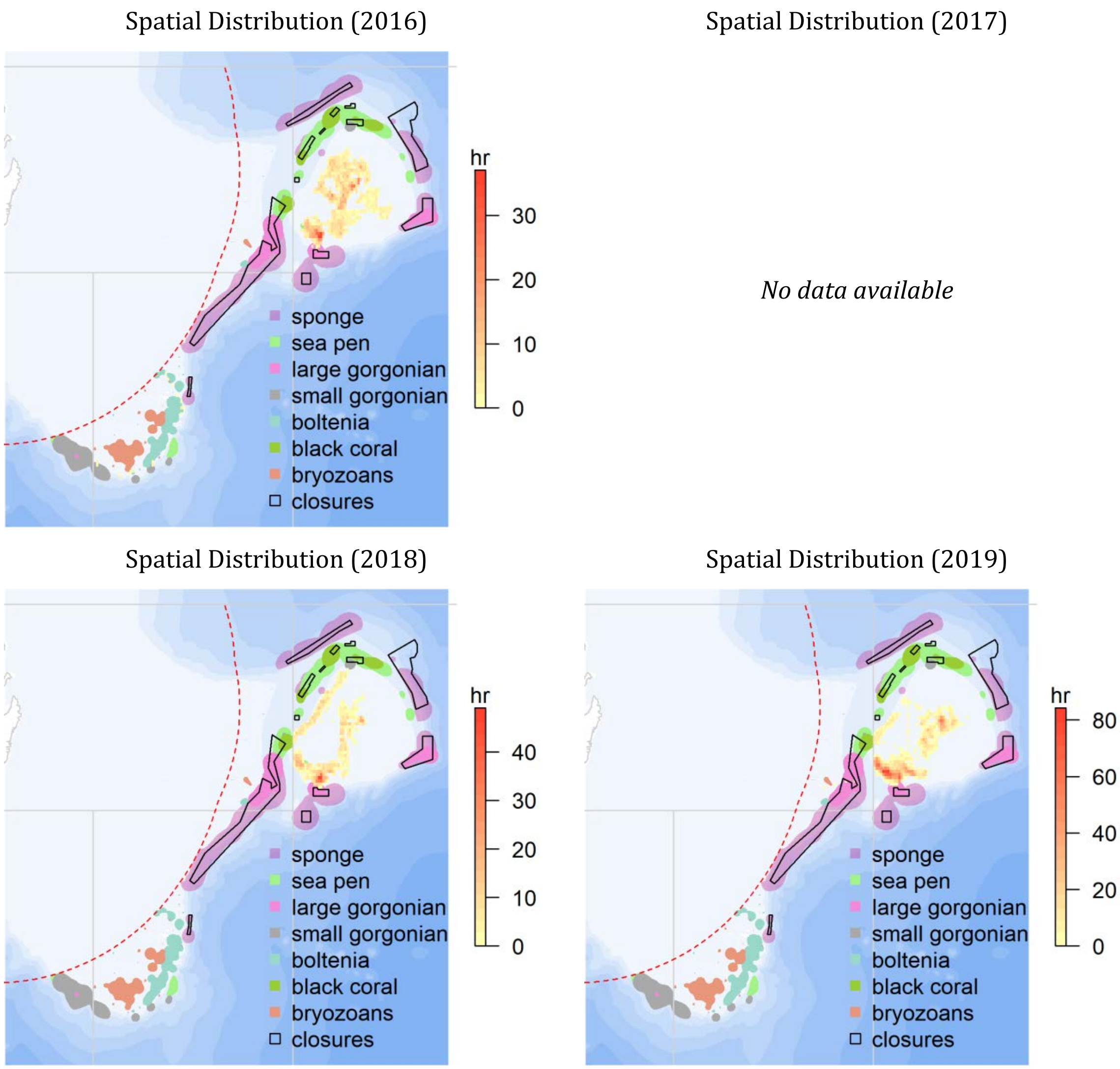


Figure 7.27. Cod 3M Longline fishery footprint together with the location of the VME polygons in the NRA, colour coded by taxon. Closed areas are indicated in black outline. Fishing activity (from yellow to red) is expressed in hours fished in each cell.

Redfish Trawl 3M (RED-OTB-3M): There are three species of Redfish in Division 3M, the deep-sea redfish (*Sebastes mentella*), acadian redfish (*Sebastes fasciatus*) and golden redfish (*Sebastes marinus*) that have been commercially fished and reported collectively as redfish in fishery statistics. Figure 7.28 shows the redfish trawl Div. 3M fishery footprint and Table 7.14 presents the main characteristics of this fishery. The fishery is conducted mainly at depths of 250-500 m in Div. 3M using demersal trawl gear with 130 mm cod-end mesh size. Records indicate that 19 vessels of different flag states participate each year and the effort of this fishery represents 14% of the total trawl effort in the NRA. Redfish is the target species (93% of the total catches) and the main bycatch species are Cod (4%) and American plaice (1%).

Table 7.14. Redfish 3M directed trawl fishery characteristics.

Target species	**Division**	**Depth (m)**	**Trawl effort (%)**	**Logbook Catch Composition (2016-2019)**	
Redfish	3M	250-500	14.1%	**Species**	**Catch (%)**
				Redfish	93.1
				Cod	4.2
Vessels / year	**Gear**	**Mean power (kW)**	**Mean length (m)**	American plaice	1.0
				Others	1.7
19	Trawl (130 mm)	1832	68		

Redfish 3M (RED-3M)

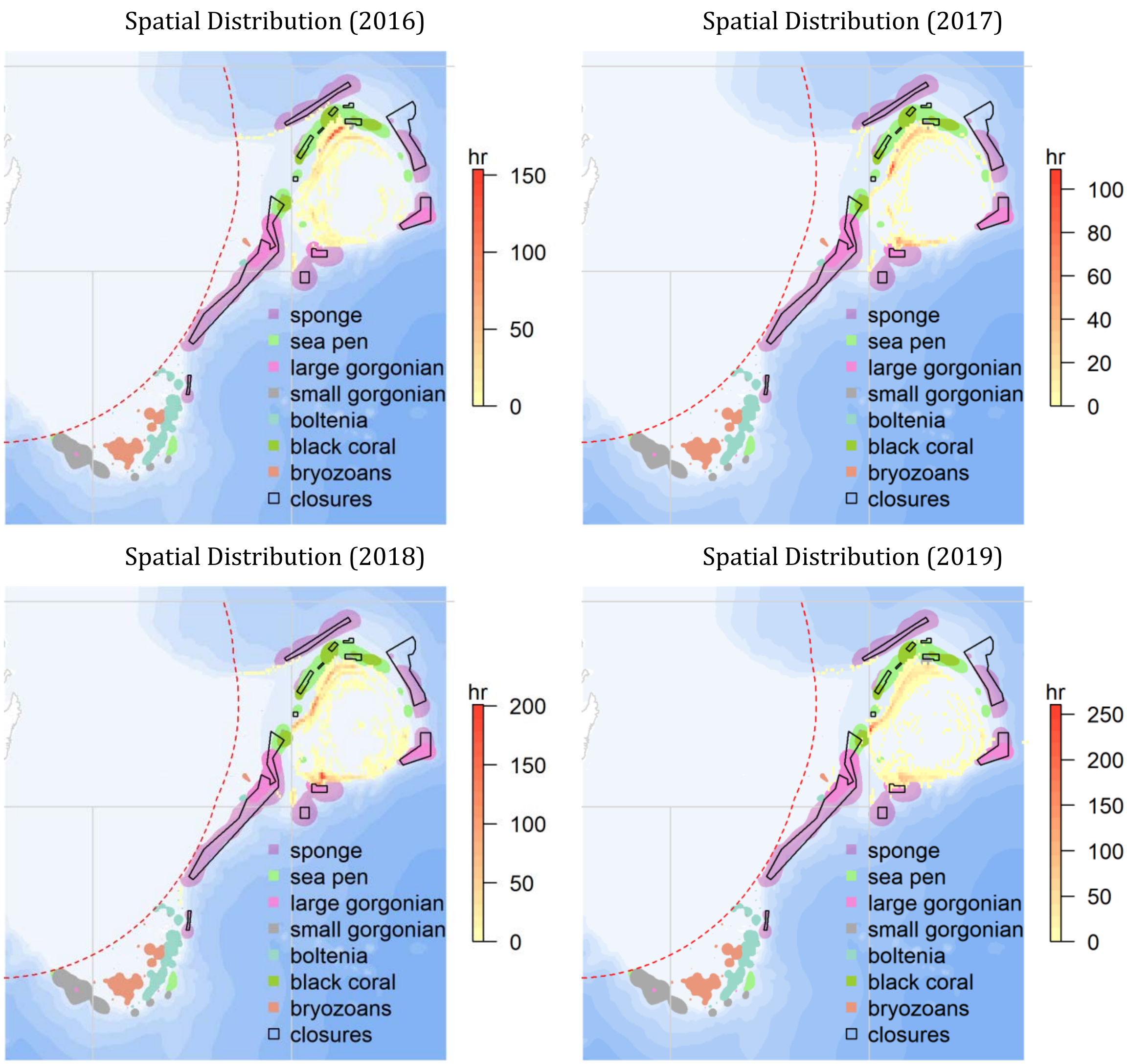


Figure 7.28. Redfish 3M fishery footprint together with the location of the VME polygons in the NRA, colour coded by taxon. Closed areas are indicated in black outline. Fishing activity (from yellow to red) is expressed in hours fished in each cell.

Divisions 3LNO

Depending on the stock and gear used there are several fisheries that take place in the portion of the 3LNO Divisions that fall within the NRA. These fisheries include some that are directed to species that are not regulated by NAFO (Silver hake and Atlantic halibut) or that are regulated but their effort is minimal due to the fact that this area is at the limit of the species distribution (White hake). Figure 7.29 shows the box plots of the depths where these fisheries are carried out.

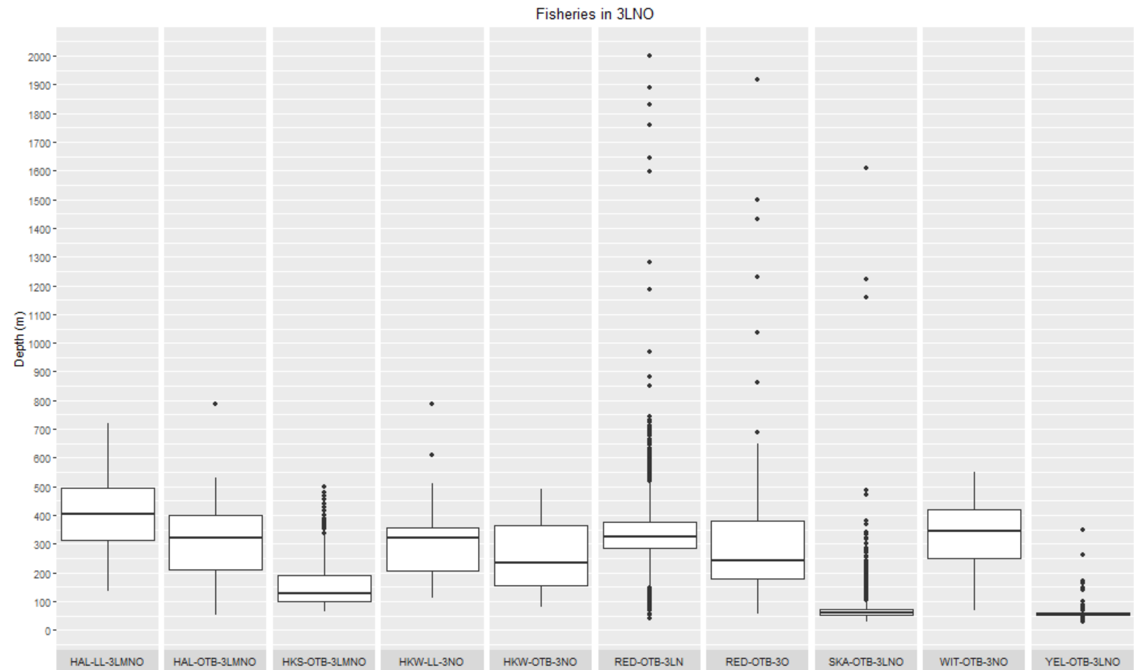


Figure 7.29. Depth box plot of the directed hauls to cod and Redfish in the NRA Div. 3M in the period 2016- 2019.

Yellowtail flounder Trawl 3LNO (YEL-OTB-3LNO): Figure 7.30 shows the Yellowtail flounder trawl NRA Divs. 3LNO fishery footprint and Table 7.15 presents the main characteristics of this fishery. The fishery is carried out mainly at depths shallower than 100 m of Divs. 3NO using demersal trawl gear with 130 mm cod-end mesh size. Records indicate that eight (8) vessels participate each year and the effort of this fishery represents 6% of the total trawl effort in the NRA. Yellowtail flounder is the target species (84% of the total catches) and the main bycatch species are American plaice (7%), Skates (3%) and Cod (1%).

Table 7.15. Yellowtail flounder 3LNO directed trawl fishery characteristics.

<table>
<tr><th>Target species</th><th>Division</th><th>Depth (m)</th><th>Trawl effort (%)</th><th colspan="2">Logbook Catch Composition (2016-2019)</th></tr>
<tr><td rowspan="3">Yellowtail flounder</td><td rowspan="3">3LNO</td><td rowspan="3">>100</td><td rowspan="3">5.8%</td><td>Species</td><td>Catch (%)</td></tr>
<tr><td>Yellowtail flounder</td><td>88.0</td></tr>
<tr><td>American plaice</td><td>6.8</td></tr>
<tr><td rowspan="2">Vessels / year</td><td rowspan="2">Gear</td><td rowspan="2">Mean power (kW)</td><td rowspan="2">Mean length (m)</td><td>Skates</td><td>3.0</td></tr>
<tr><td>Cod</td><td>1.2</td></tr>
<tr><td rowspan="3">8</td><td rowspan="3">Trawl (130 mm)</td><td rowspan="3">1809</td><td rowspan="3">62</td><td>Others</td><td>1.0</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

Yellowtail flounder (YEL)

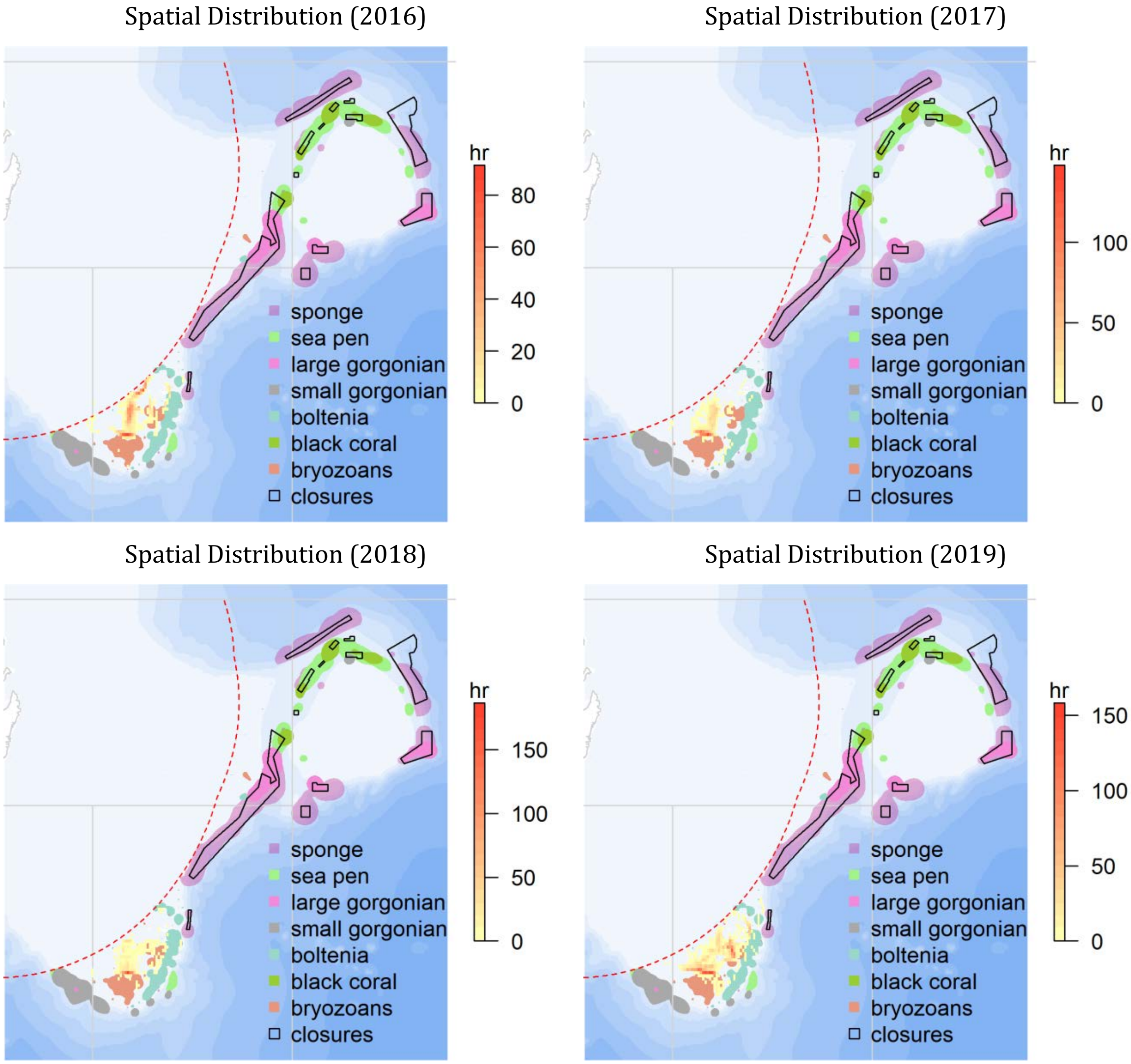


Figure 7.30. Yellowtail flounder fishery footprint together with the location of the VME polygons in the NRA, colour coded by taxon. Closed areas are indicated in black outline. Fishing activity (from yellow to red) is expressed in hours fished in each cell.

Skates Trawl 3LNO (SKA-OTB-3LNO): Commercial catches of skates comprise a mix of species (*Amblyraja radiata*, *Bathyraja spinicauda*, *Raja hyperborean*, *Raja senta*, etc). However, thorny skate dominates the catches, comprising around 90% of the total. Figure 7.31 shows the skates trawl NRA Div. 3LNO fishery footprint and Table 7.16 presents the main characteristics of this fishery. The fishery is conducted mainly at depths shallower than 100 m of Divs. 3NO using demersal trawl gear with 280 mm cod-end mesh size. Records indicate that 12 vessels of different flag states participate each year and the effort of this fishery represents 9% of the total trawl effort in the NRA. Skates are the target species (83% of the total catches) and the main bycatch species are Yellowtail flounder (7%), American plaice (4%), Cod (3%) and Atlantic halibut (1%).

Table 7.16. Skates 3LNO directed trawl fishery characteristics.

Target species	Division	Depth (m)	Trawl effort (%)	Logbook Catch Composition (2016-2019)	
				Species	**Catch (%)**
Skates	3LNO	>100	9.2%	Skates	83.4
				Yellowtail flounder	7
Vessels / year	**Gear**	**Mean power (kW)**	**Mean length (m)**	American plaice	4
				Cod	2.8
12	Trawl (280 mm)	1656	66	Atlantic halibut	1.2
				Others	1.6

Skates (SKA)

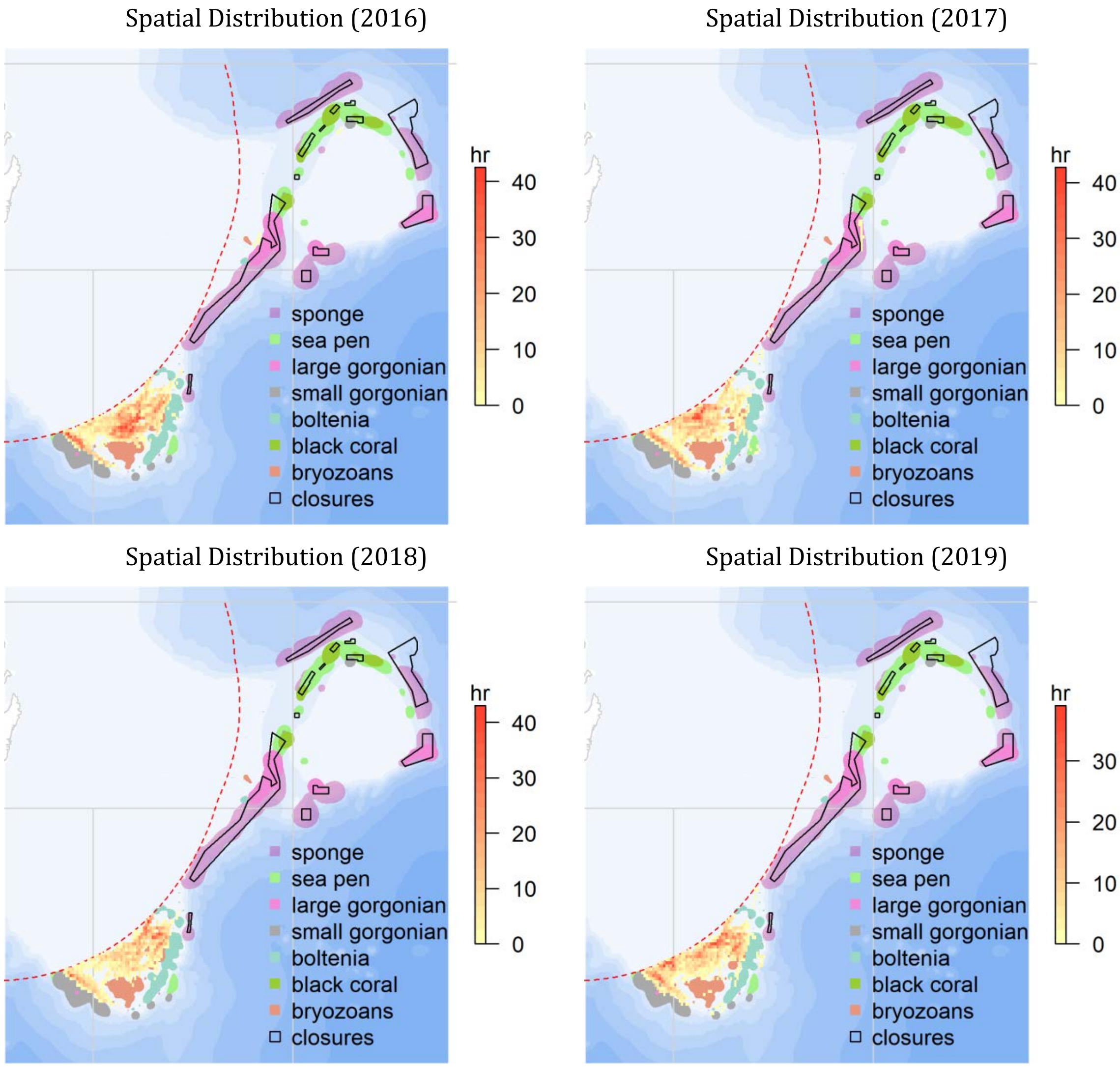


Figure 7.31. Skates fishery footprint together with the location of the VME polygons in the NRA, colour coded by taxon. Closed areas are indicated in black outline. Fishing activity (from yellow to red) is expressed in hours fished in each cell.

Witch flounder Trawl 3NO (WIT-OTB-3NO): This fishery represents a small percentage of the total effort due to the low abundance of this species in the area. Figure 7.32 shows the Witch flounder trawl NRA Divs. 3NO fishery footprint and Table 7.17 presents the main characteristics of this fishery. The fishery is carried out mainly at depths between 250-450 m of Divs. 3NO using demersal trawl gear with 130 mm cod-end mesh size. Records indicate that 4 vessels participate each year and the effort of this fishery represents 0.3% of the total trawl effort in the NRA. Witch flounder is the target species (70% of the total catches) and the main bycatch species are Redfish (7%), Skates (7%), Atlantic halibut (7%) and American plaice (3%). Figure 7.32 shows some directed hauls to this species in Div. 3M, although the fishery for this species in Div. 3M is not regulated.

Table 7.17. Witch flounder 3NO directed trawl fishery characteristics.

<table>
<tr><th>Target species</th><th>Division</th><th>Depth (m)</th><th>Trawl effort (%)</th><th colspan="2">Logbook Catch Composition (2016-2019)</th></tr>
<tr><td rowspan="3">Witch flounder</td><td rowspan="3">3NO</td><td rowspan="3">250-450</td><td rowspan="3">0.3%</td><td>Species</td><td>Catch (%)</td></tr>
<tr><td>Witch flounder</td><td>70.1</td></tr>
<tr><td>Redfish</td><td>7.4</td></tr>
<tr><td rowspan="2">Vessels / year</td><td rowspan="2">Gear</td><td rowspan="2">Mean power (kW)</td><td rowspan="2">Mean length (m)</td><td>Skates</td><td>7.1</td></tr>
<tr><td>Atlantic halibut</td><td>6.8</td></tr>
<tr><td rowspan="3">4</td><td rowspan="3">Trawl (130 mm)</td><td rowspan="3">1626</td><td rowspan="3">71</td><td>American Plaice</td><td>3.2</td></tr>
<tr><td>Cod</td><td>2.6</td></tr>
<tr><td>Others</td><td>2.8</td></tr>
</table>

Witch flounder (WIT)

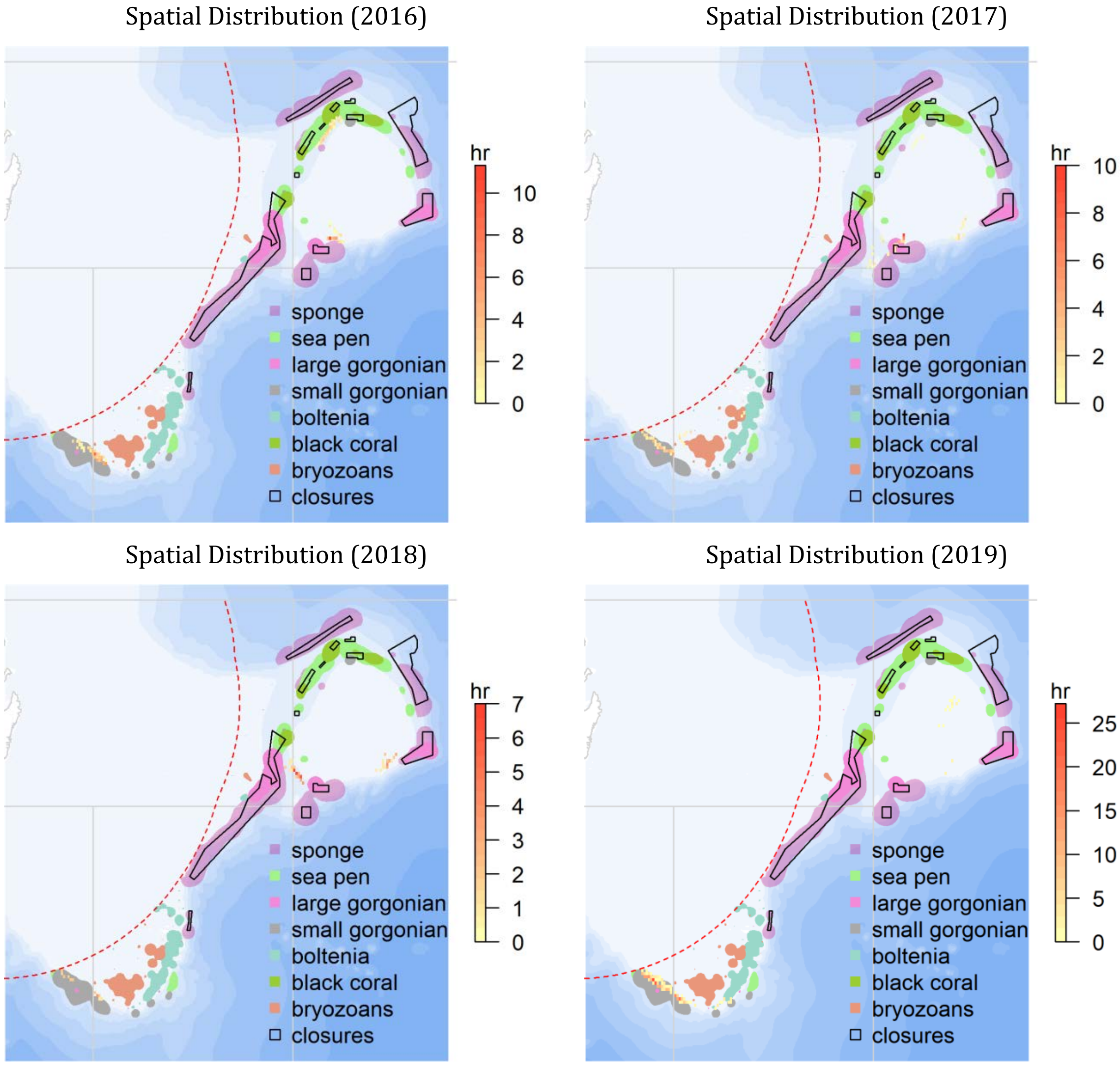


Figure 7.32. Witch flounder fishery footprint together with the location of the VME polygons in the NRA, colour coded by taxon. Closed areas are indicated in black outline. Fishing activity (from yellow to red) is expressed in hours fished in each cell.

<u>White hake Trawl 3NO (HKW-OTB-3NO)</u>: This fishery represents a small percentage of the total effort due to the fact that NRA Divs. 3NO is at the limit of the species distribution and this species appears sporadically in the area. Figure 7.33 shows the White hake trawl NRA Divs. 3NO fishery footprint and Table 7.18 presents the main characteristics of this fishery. In the period 2016-2019 there are only two years (2016 and 2018) with trawl hauls directed at this species. The fishery is carried out mainly at depths between 150-350 m of Divs. 3NO using demersal trawl gear with 130 mm cod-end mesh size. Records indicate that eight (8) vessels of different flag states participate each year and the effort of this fishery represents 0.1% of the total trawl effort in the NRA. White hake is the target species (50% of the total catches) and the main bycatch species are Redfish (16%), Silver hake (11%), Witch flounder (5%) and Atlantic halibut (5%).

Table 7.18. White hake 3NO directed trawl fishery characteristics.

<table>
<tr><th>Target species</th><th>Division</th><th>Depth (m)</th><th>Trawl effort (%)</th><th colspan="2">Logbook Catch Composition (2016-2019)</th></tr>
<tr><td rowspan="3">White hake</td><td rowspan="3">3NO</td><td rowspan="3">150-350</td><td rowspan="3">0.1%</td><td>Species</td><td>Catch (%)</td></tr>
<tr><td>White hake</td><td>49.8</td></tr>
<tr><td>Redfish</td><td>16</td></tr>
<tr><td rowspan="2">Vessels / year</td><td rowspan="2">Gear</td><td rowspan="2">Mean power (kW)</td><td rowspan="2">Mean length (m)</td><td>Silver hake</td><td>11.6</td></tr>
<tr><td>Witch flounder</td><td>4.8</td></tr>
<tr><td rowspan="3">8</td><td rowspan="3">Trawl (130 mm)</td><td rowspan="3">1484</td><td rowspan="3">64</td><td>Atlantic halibut</td><td>4.7</td></tr>
<tr><td>Northern squid</td><td>3.5</td></tr>
<tr><td>Others</td><td>9.6</td></tr>
</table>

White hake (HKW)

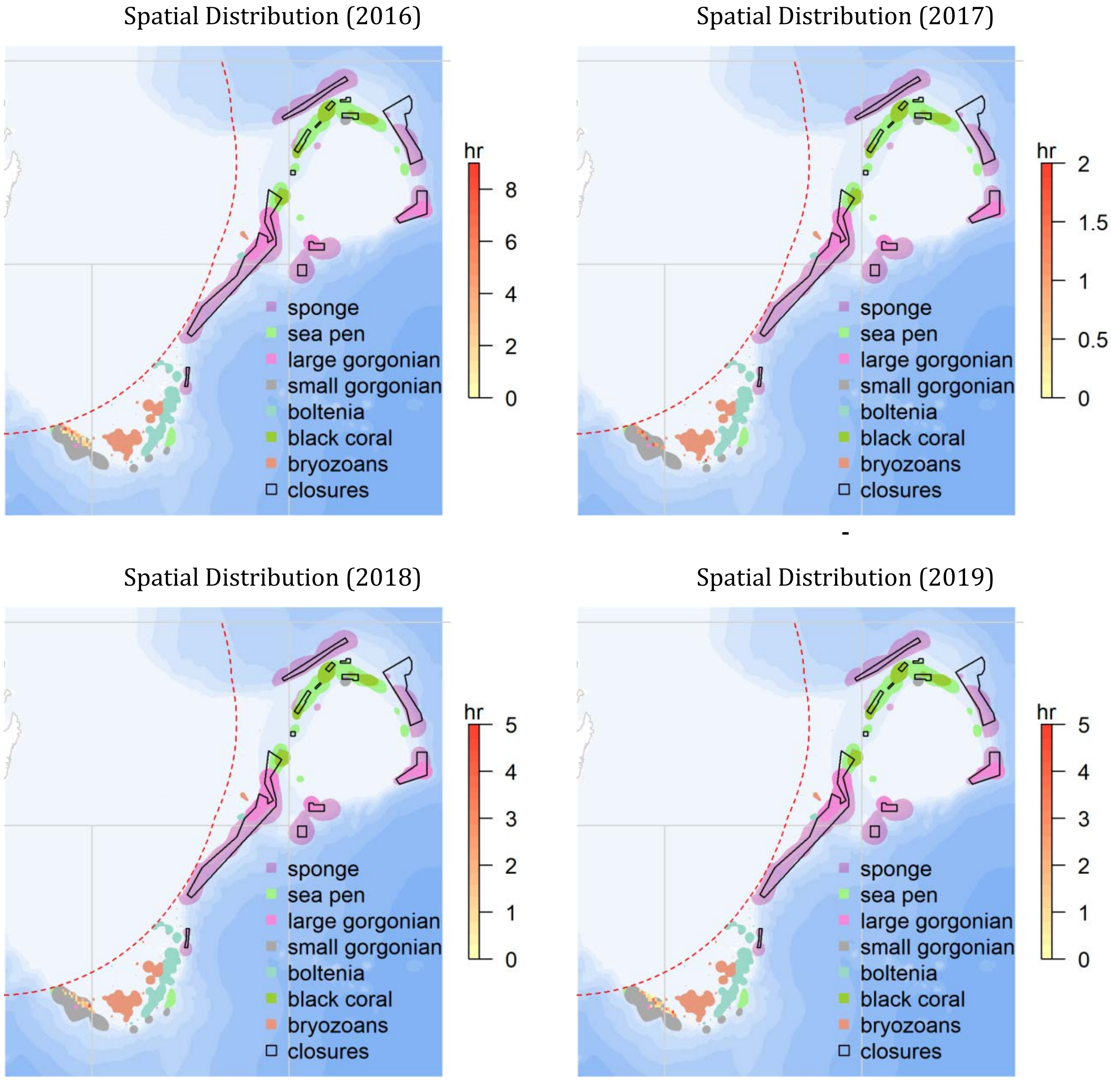


Figure 7.33. White hake fishery footprint together with the location of the VME polygons in the NRA, colour coded by taxon. Closed areas are indicated in black outline. Fishing activity (from yellow to red) is expressed in hours fished in each cell.

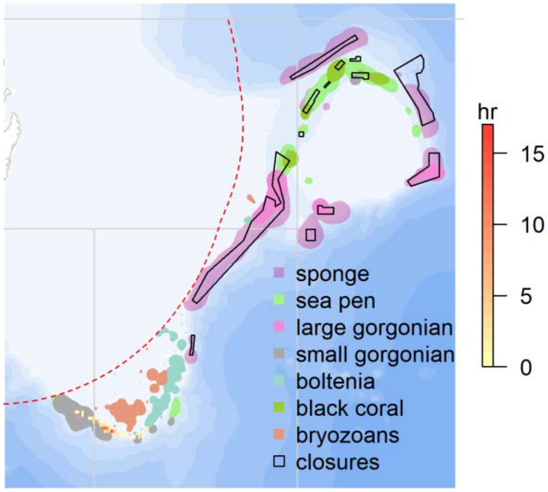
<u>White hake longline 3NO (HKW-LL-3NO)</u>: This fishery represents a small percentage of the total effort because the NRA Divs. 3NO is at the limit of the species distribution and this species appears sporadically in the area. Figure 7.34 shows the White hake longline NRA Divs. 3NO fishery footprint and Table 7.19 presents the main characteristics of this fishery. In the period 2016-2019 there are only two years (2016 and 2018) with longline hauls directed at this species. The fishery is conducted mainly at depths of 200-350 m in Divs. 3NO using demersal longline gear. Records indicate that two (2) vessels participate each year and the effort of this fishery represents 4.4% of the total longline effort in the NRA. White hake is the target species (60% of the total catches) and the main bycatch species are Atlantic halibut (16%), Cod (8%), Skates (7%) and Porbeagle (2%).

Table 7.19. White hake 3NO directed longline fishery characteristics.

Target species	**Division**	**Depth (m)**	**Longline effort (%)**	**Logbook Catch Composition (2016-2019)**	
White hake	3NO	200-350	4.4%	Species	Catch (%)
				White hake	59.3
				Atlantic halibut	16.2
Vessels / year	**Gear**	**Mean power (kW)**	**Mean length (m)**	cod	7.7
				skates	7.5
2	Longline	590	38	Porbeagle	2.1
				Wolffishes	2.0
				Others	5.2

White hake (HKW-LL)

Spatial Distribution (2016)	Spatial Distribution (2017)



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Spatial Distribution (2018)	Spatial Distribution (2019)

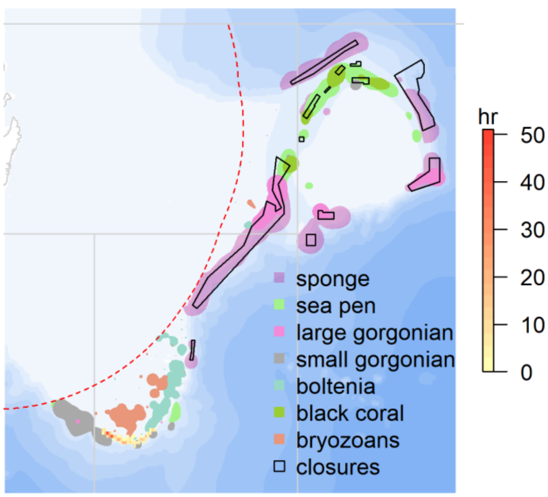

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Figure 7.34. White hake longline fishery footprint together with the location of the VME polygons in the NRA, colour coded by taxon. Closed areas are indicated in black outline. Fishing activity (from yellow to red) is expressed in hours fished in each cell.

<u>Redfish Trawl 3LN (RED-OTB-3LN)</u>: There are two species of redfish in Divisions 3L and 3N, the deep-sea redfish (*Sebastes mentella*) and the Acadian redfish (*Sebastes fasciatus*) that have been commercially fished and reported collectively as redfish in fishery statistics. Both species are managed as a single stock in Divs. 3LN. Figure 7.35 shows the redfish trawl NRA Divs. 3LN fishery footprint and Table 7.20 presents the main characteristics of this fishery. The fishery is conducted mainly with depths ranging from 250-350 m in Divs. 3LN using demersal trawl gear with 130 mm cod-end mesh size. Records indicate that 20 vessels of different flag states participate each year and the effort of this fishery represents 10% of the total trawl effort in the NRA. Redfish is the target species (92% of the total catches) and the main bycatch species are Cod (2%), Atlantic halibut (2%) and American plaice (2%).

Table 7.20. Redfish 3LN directed trawl fishery characteristics.

Target species	**Division**	**Depth (m)**	**Trawl effort (%)**	**Logbook Catch Composition (2016-2019)**	
Redfish	3LN	250-350	10%	**Species**	**Catch (%)**
				Redfish	92.5
				Cod	2.3
Vessels / year	**Gear**	**Mean power (kW)**	**Mean length (m)**	Atlantic halibut	1.8
				American plaice	1.8
20	Trawl (130 mm)	1981	65	Others	1.6

Redfish Trawl 3O (RED-OTB-3O): There are two species of redfish in Division 3O, the deep-sea redfish (*Sebastes mentella*) and the Acadian redfish (*Sebastes fasciatus*) that have been commercially fished and reported collectively as redfish in fishery statistics. Both species are managed as a single stock in Div. 3O. Figure 7.35 shows the redfish trawl NRA Div. 3O fishery footprint and Table 7.21 presents the main characteristics of this fishery. The fishery is carried out mainly at depths ranging from 200 to 350 m in Div. 3O using demersal trawl gear with 130 mm cod-end mesh size. Records indicate that 18 vessels of different flag states participate each year and the effort of this fishery represents 10% of the total trawl effort in the NRA. Redfish is the target species (88% of the total catches) and the main bycatch species are Silver hake (2%), American plaice (2%), Atlantic halibut (2%) and Cod (2%).

Table 7.21. Redfish 3O directed trawl fishery characteristics.

Target species	**Division**	**Depth (m)**	**Trawl effort (%)**	**Logbook Catch Composition (2016-2019)**	
Redfish	3O	200-350	10%	Species	Catch (%)
				Redfish	87.6
				Silver hake	2.5
Vessels / year	**Gear**	**Mean power (kW)**	**Mean length (m)**	American plaice	2.2
				Atlantic halibut	1.9
18	Trawl (130 mm)	1669	66	Cod	1.8
				White hake	1.1
				Others	2.9

Redfish 3LNO (RED-3LNO)

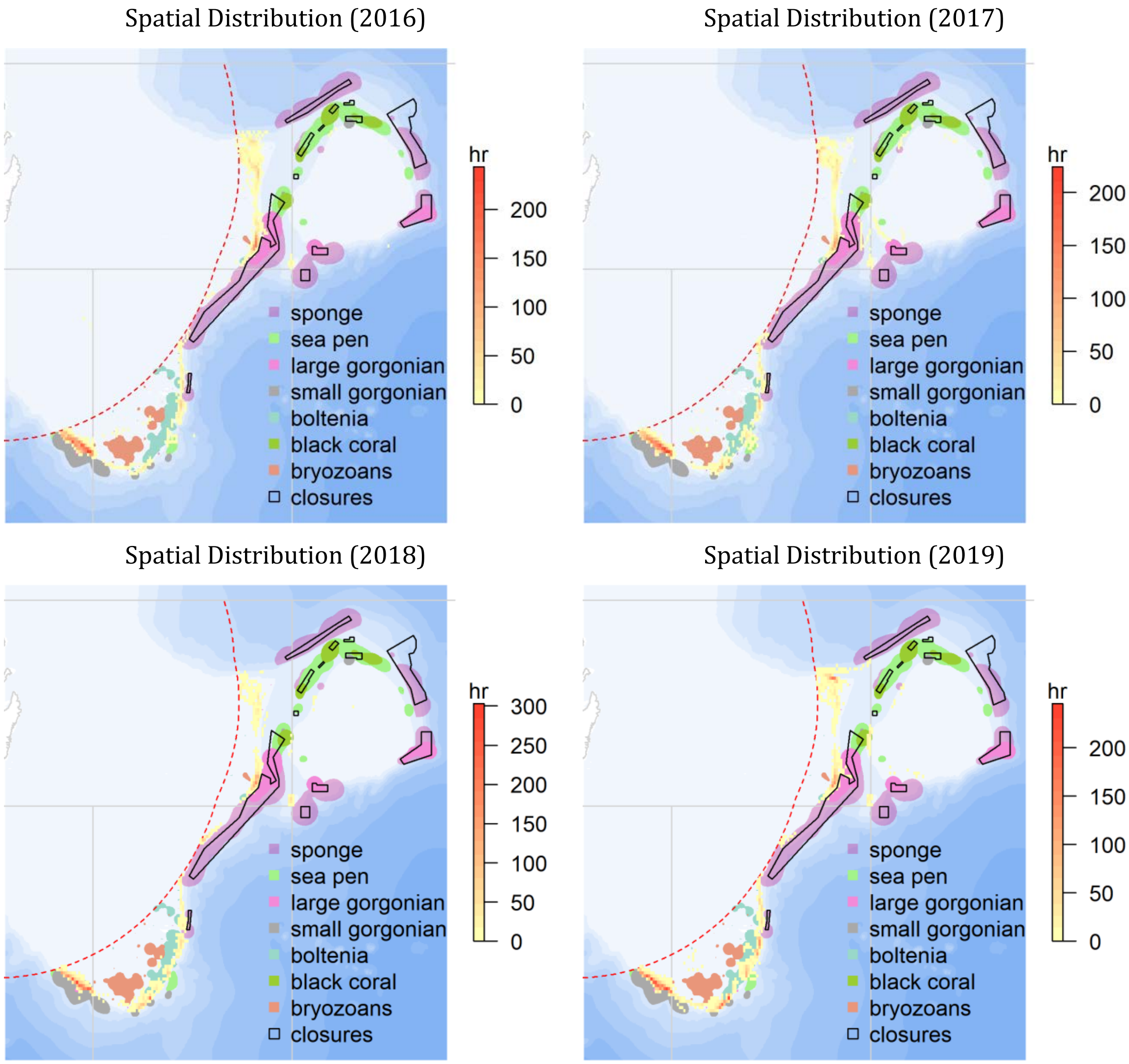


Figure 7.35. Redfish 3LNO fishery footprint together with the location of the VME polygons in the NRA, colour coded by taxon. Closed areas are indicated in black outline. Fishing activity (from yellow to red) is expressed in hours fished in each cell.

In addition to these regulated fisheries, there are other bottom fisheries in NRA Divs. 3LNO not regulated by NAFO, mainly targeting Atlantic halibut and Silver hake.

<u>Atlantic halibut Trawl 3LNO (HAL-OTB-3LMNO)</u>: Figure 7.36 shows the Atlantic halibut trawl NRA footprint and Table 7.22 presents the main characteristics of this fishery. The fishery is carried out mainly at depths ranging from 200 to 400 m in Divs. 3LNO using demersal trawl gear. In 2019 there were not directed trawl hauls to this species. Occasionally trawl hauls targeting this species have been observed in Div. 3M. Records indicate that seven (7) trawl vessels of different flag states participate each year and the effort of this fishery represents 0.2% of the total trawl effort in the NRA. Atlantic halibut is the target species (60% of the total catches) and the main bycatch species are Redfish (14%), White hake (7%), Silver hake (6%) and Witch flounder (4%).

Table 7.22. Atlantic halibut 3LNO directed trawl fishery characteristics.

<table>
<tr><th rowspan="2">Target species</th><th rowspan="2">Division</th><th rowspan="2">Depth (m)</th><th rowspan="2">Trawl effort (%)</th><th colspan="2">Logbook Catch Composition (2016-2019)</th></tr>
<tr><th>Species</th><th>Catch (%)</th></tr>
<tr><td rowspan="2">Atlantic halibut</td><td rowspan="2">3LNO</td><td rowspan="2">200- 400</td><td rowspan="2">0.2%</td><td>Atlantic halibut</td><td>60.1</td></tr>
<tr><td>Redfish</td><td>13.8</td></tr>
<tr><th rowspan="2">Vessels / year</th><th rowspan="2">Gear</th><th rowspan="2">Mean power (kW)</th><th rowspan="2">Mean length (m)</th><td>White hake</td><td>6.6</td></tr>
<tr><td>Silver hake</td><td>6.2</td></tr>
<tr><td rowspan="3">7</td><td rowspan="3">Trawl (130 mm)</td><td rowspan="3">1913</td><td rowspan="3">67</td><td>Witch flounder</td><td>3.7</td></tr>
<tr><td>Cod</td><td>2.7</td></tr>
<tr><td>Others</td><td>6.9</td></tr>
</table>

Atlantic halibut (HAL)

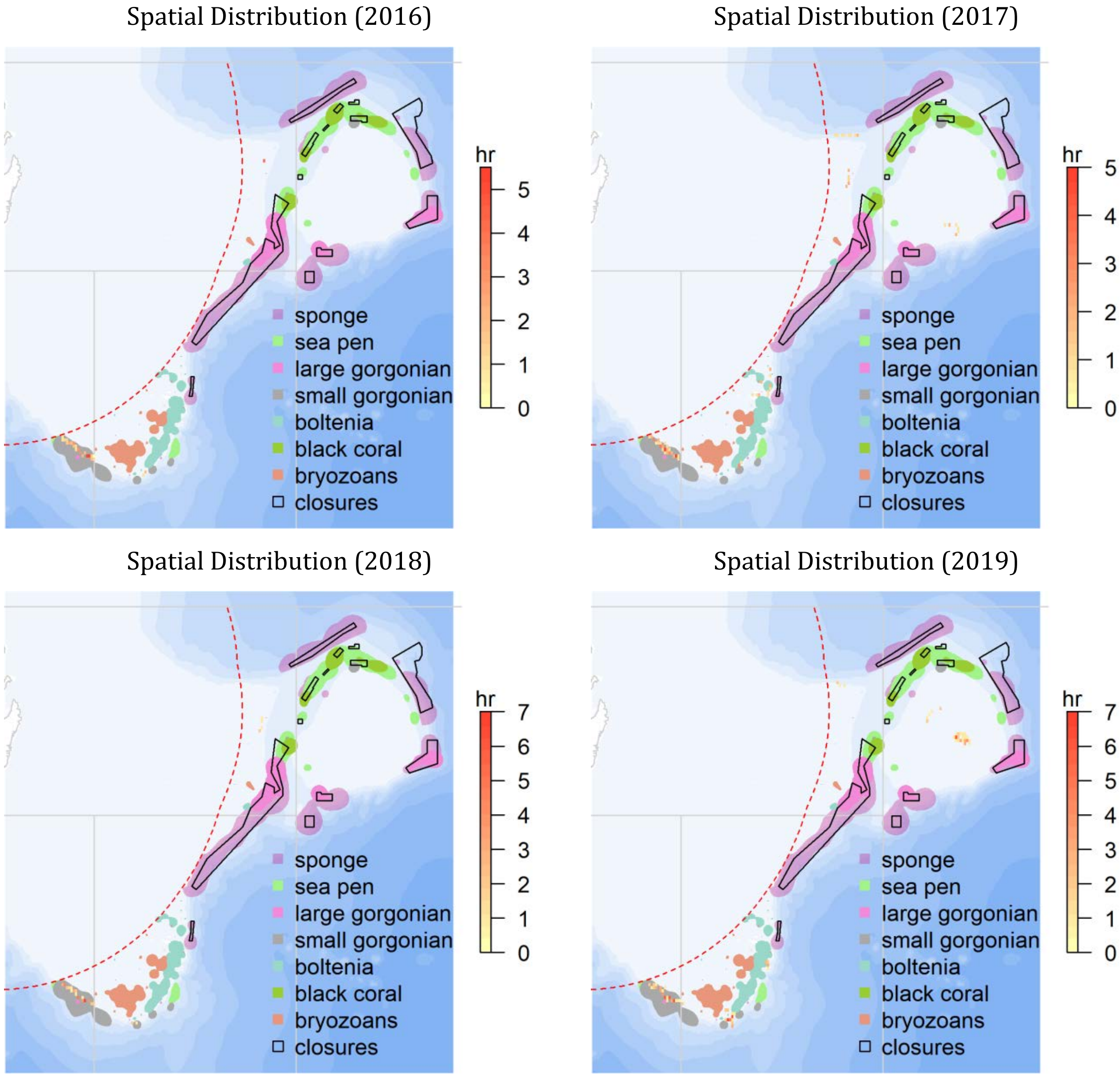


Figure 7.36. Atlantic halibut fishery footprint together with the location of the VME polygons in the NRA, colour coded by taxon. Closed areas are indicated in black outline. Fishing activity (from yellow to red) is expressed in hours fished in each cell.

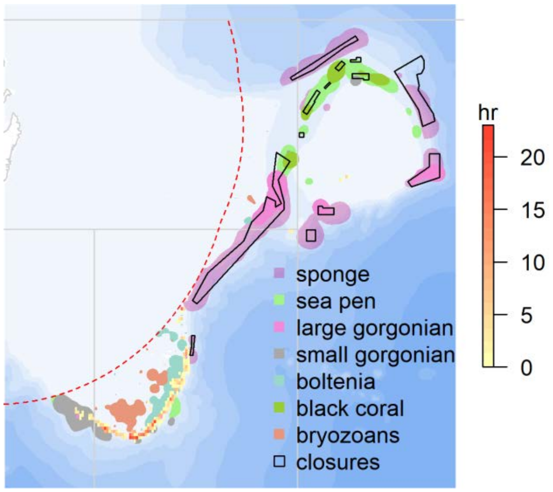
<u>Atlantic halibut longline 3LNO (HAL-LL-3LMNO)</u>: Figure 7.37 shows the Atlantic halibut longline NRA footprint and Table 7.23 presents the main characteristics of this fishery. The fishery is carried out mainly at depths ranging from 300 to 500 m in Div. 3N using demersal longline gear. In 2019 there were not directed longline hauls to this species. Records indicate that two (2) vessels participate each year and the effort of this fishery represents 20% of the total longline effort in the NRA. Atlantic halibut is the target species (59% of the total catches) and the main bycatch species are White hake (12%), Roundnose grenadier (4%), cod (4%) and Wolffishes (3%).

Table 7.23. Atlantic halibut 3LNO directed trawl fishery characteristics.

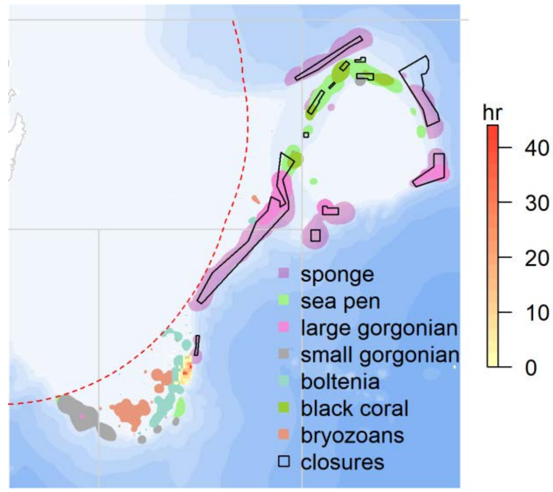
Target species	**Division**	**Depth (m)**	**Longline effort (%)**	**Logbook Catch Composition (2016-2019)**	
				Species	**Catch (%)**
Atlantic halibut	3LNO	200-400	20%	Atlantic halibut	59
				White hake	11.6
Vessels / year	**Gear**	**Mean power (kW)**	**Mean length (m)**	Roundnose grenadier	3.6
				Cod	3.6
7	Longline	640	30	Wolffishes	3.4
				Others	18.8

Atlantic Halibut (HAL-LL)

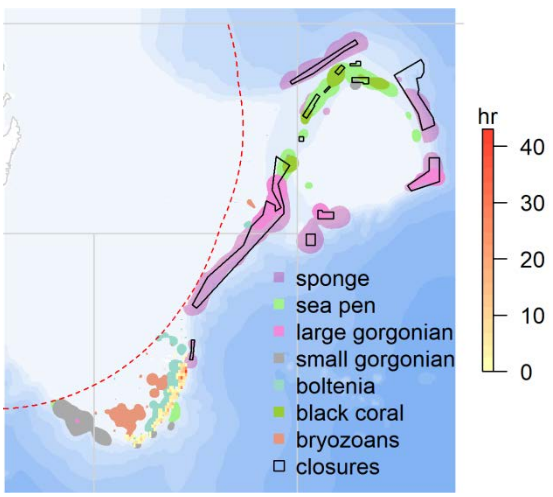
Spatial Distribution (2016)



Spatial Distribution (2017)



Spatial Distribution (2018)



Spatial Distribution (2019)

-

Figure 7.37. Atlantic halibut longline fishery footprint together with the location of the VME polygons in the NRA, colour coded by taxon. Closed areas are indicated in black outline. Fishing activity (from yellow to red) is expressed in hours fished in each cell.

Silver hake Trawl 3LNO (HKS-OTB-3LMNO): This fishery represents a small percentage of the total effort because the NRA Divs. 3LNO is at the limit of the species distribution and this species appears sporadically in the area. Figure 7.38 shows the Silver hake trawl NRA Divs. 3LNO fishery footprint and Table 7.24 presents the main characteristics of this fishery. The fishery is conducted mainly at depths ranging from 100 to 200 m in Divs. 3NO using demersal trawl gear. Records indicate that eight (8) vessels of different flag states participate each year and the effort of this fishery represents 1.1% of the total trawl effort in the NRA. Silver hake is the target species (73% of the total catches) and the main bycatch species are Redfish (12%), Northern squid (5%), White hake (4%), and Skates (2%).

Table 7.24. Silver hake 3LNO directed trawl fishery characteristics.

<table>
<tr><th>Target species</th><th>Division</th><th>Depth (m)</th><th>Trawl effort (%)</th><th colspan="2">Logbook Catch Composition (2016-2019)</th></tr>
<tr><td rowspan="3">Silver hake</td><td rowspan="3">3NO</td><td rowspan="3">100-200</td><td rowspan="3">1.1%</td><td>Species</td><td>Catch (%)</td></tr>
<tr><td>Silver hake</td><td>73</td></tr>
<tr><td>Redfish</td><td>12.1</td></tr>
<tr><td rowspan="2">Vessels / year</td><td rowspan="2">Gear</td><td rowspan="2">Mean power (kW)</td><td rowspan="2">Mean length (m)</td><td>Northern squid</td><td>5.5</td></tr>
<tr><td>White hake</td><td>3.7</td></tr>
<tr><td rowspan="3">8</td><td rowspan="3">Trawl (130 mm)</td><td rowspan="3">1658</td><td rowspan="3">65</td><td>Skates</td><td>1.6</td></tr>
<tr><td>Atlantic halibut</td><td>1.1</td></tr>
<tr><td>Others</td><td>3.0</td></tr>
</table>

Silver hake (HKS)

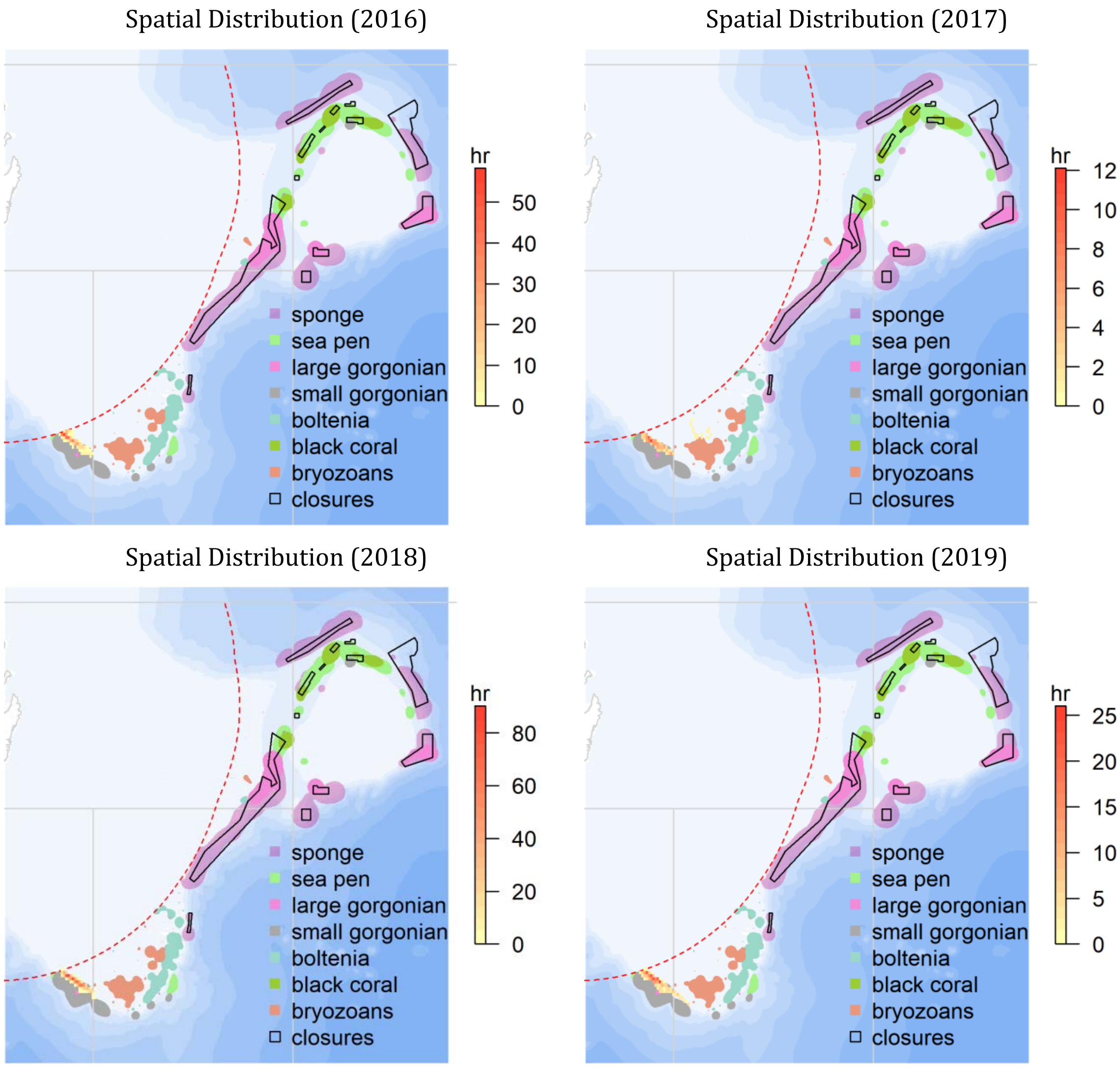


Figure 7.38. Silver hake fishery footprint together with the location of the VME polygons in the NRA, colour coded by taxon. Closed areas are indicated in black outline. Fishing activity (from yellow to red) is expressed in hours fished in each cell.

Acknowledgements

This work was conducted as part of the NEREIDA project funded by the European Commission under Grant Agreements SI2.770786; SI2.793318 and SI2.827558.

iv) Overlap of demersal fisheries with VMEs

We conducted a simple overlay analysis to estimate the area of VME polygons that is overlapped by the 2016 to 2019 cumulative fishing effort and fisheries-specific effort layers (shown in Section 7.c)iii). The fishing effort layers used were calculated with the new "*Coupling VMS with Logbook*" methodology described in Section 7.c)ii.

Figure 7.39 illustrates the VME polygons generated in 2013 together with those generated in 2019 and areas of overlap identified between both years. The overlay analysis done within this Section was carried out according to 2019 VME taxa polygons.

Table 7.25 contains the list of species with the corresponding 3-Alpha Code, Common English Name and Scientific Name whose fisheries were described for the period 2016-2019 and referred in the X axis of Figure 7.40 to Figure 7.43.

Table 7.25. List of species

3-Alpha Code	Common English Name	Scientific Name
CAB-LL[61]	Northern wolffish	*Anarhichas denticulatus*
COD-LL	Atlantic Cod	*Gadus morhua*
COD-OTB[62]	Atlantic Cod	*Gadus morhua*
GHL	Greenland halibut	*Reinhardtius hippoglossoides*
GSK	Boreal (Greenland) shark	*Somniosus microcephalus*
HAD	Haddock	*Melanogrammus aeglefinus*
HAL	Atlantic halibut	*Hippoglossus hippoglossus*
HAL-LL	Atlantic halibut	*Hippoglossus hippoglossus*
HKS	Silver hake	*Merluccius bilinearis*
HKW	White hake	*Urophycis tenuis*
HKW-LL	White hake	*Urophycis tenuis*
PLA	American Plaice	*Hippoglossoides platessoides*
RED	Redfish	*Sebastes sp.*
SKA	Skates	*Raja sp.*
SQI	Northern squid	*Illex illecebrosus*
WIT	Witch flounder	*Glyptocephalus cynoglossus*
YEL	Yellowtail flounder	*Limanda ferruginea*

61 LL: Longline
62 OTB: Bottom Otter Trawl

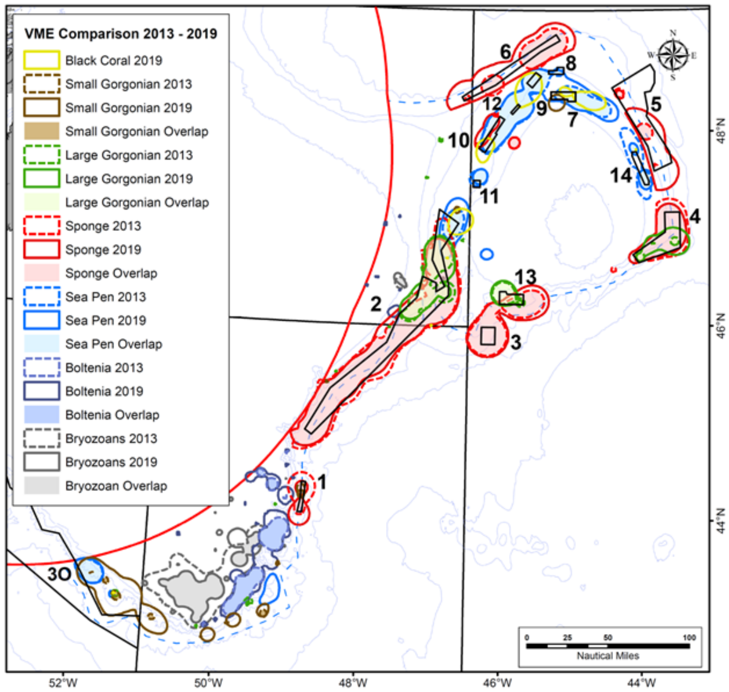


Figure 7.39. Overview map of the location of VME taxa (large-sized sponges, sea pens, small gorgonian corals, large gorgonian corals, erect bryozoans, sea squirts (*Boltenia ovifera*), and black corals) in the NRA, colour coded by taxon. For all taxa the polygons determined from the 2013 analysis are shown in dashed line and compared with those from the 2019 analyses in solid lines. Areas of overlap between both years (2013 and 2019) are shaded. The closed areas are indicated in black outline and their numbers shown near the closure. Dashed blue line is the fishing footprint (NAFO, 2019).

To perform this analysis we measured: 1) the area (km^2) of each of the seven 2019 VME taxa polygons and all VMEs polygons merged; 2) the area (km^2) that coincides for all VME combinations, fisheries-specific footprints and cumulative fishing footprint, expressed as the percent VME overlapped by a given fishery. The areas of 2019 VME polygons (km^2) are shown in Table 7.26.

Table 7.26. Area in Km^2 of each of the VME taxa polygons

VME polygon	VME_km^2
All VME Polygons (merged)	44810.7
Black Corals	2631.1
Boltenias	4076.7
Bryozoans	3491.5
Large Gorgonians	5006.6
Sea Pens	8497.6
Small Gorgonians	4540.2
Sponges	24217.8

The top panel of the following figures (Figure 7.30 to Figure 7.43) represent the area of all VMEs combined, and the bottom seven panels represent the specific VME polygons by taxa. The number on top of each bar represents the absolute area of VME (km^2) that is overlapped by the fishing effort layers. Note that VME polygons are not the same as the VME closure areas.

Overall, we found that the total VME area was subject to fishing activity in the 4 years considered in this analysis, with an average overlap of 25.5% (see Figure 7.30 to Figure 7.43 and Table 7.27). The average overlap was lowest for sponges (15.4%), large gorgonians (21.1%) and black coral (22.4%) and increasingly so for sea pens (28.8%), bryozoans (38.6%), small gorgonians (41.2%) and Boltenia (45.2%). There was considerable year-to-year variability in overlap, in terms of the difference between minimum and maximum, for sea pens (9.5%), large gorgonians (11.6%), bryozoans (14.4%) and Boltenia (29.7%), but considerably lower (<5%) for black corals (3.4%), small gorgonians (4.6%) and sponges (4.7%).

Table 7.27. Percentage of VME area overlapped with the cumulative fisheries per year

	Percentage of VME overlapped (%) with cumulative fisheries			
VME	**2016**	**2017**	**2018**	**2019**
All VMEs combined	23.1	23.2	27.3	28.3
Black Corals	20.3	21.8	23.7	23.6
Boltenia	29.3	43.5	48.9	59
Bryozoans	38.7	32.4	36.6	46.8
Large gorgonians	18.5	18.8	17.7	29.3
Seapens	27.5	27	33.9	24.4
Small gorgonians	39.8	40.5	44.4	40
Sponges	14.7	13	16	17.7

In general terms, the Greenland halibut fishery had the greatest area overlap with the KDE VME polygons, for each of the VME taxa: Black corals (16.6% to 20.7%), Boltenia (0.9% to 7.8%), Bryozoa (0.1% to 0.4%), Large gorgonians (6.5% to 11%), Sea pens (19.7% to 29.7%), Small gorgonians (8.7% to 11.6%), Sponges (11.8% to 14.1%). Redfish 3LNO together with Skates fisheries had the next largest overlap in the seven (7) VME types.

The fishing effort overlay analysis using the new "*Coupling VMS with Logbook*" methodology on 2016 to 2019 data are in agreement with results of the previous WG-ESA meeting (NAFO 2016) where the overlay analysis was conducted on fishing for the 2012-2015-time period. This new analysis was done by taking into account seven VME taxa polygons instead of three VME taxa polygons used in the past.

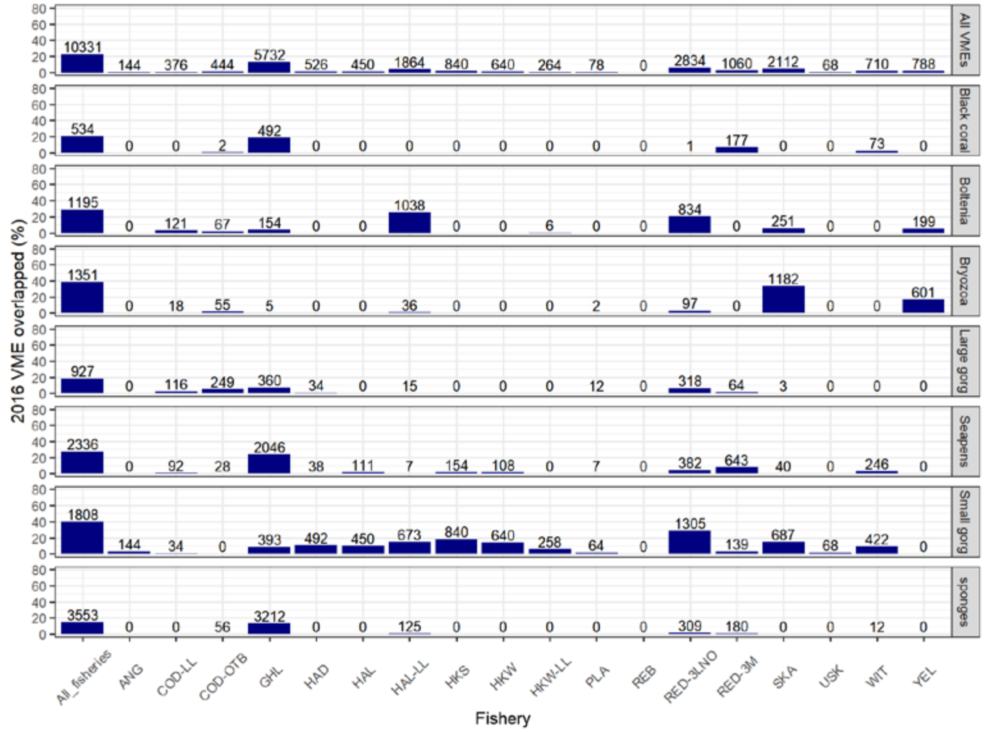


Figure 7.40. Percentage of VME polygon overlapped by cumulative fisheries (far-left bars) and fisheries-specific effort areas using the new "*Coupling VMS with Logbook*" methodology for **2016 year.**

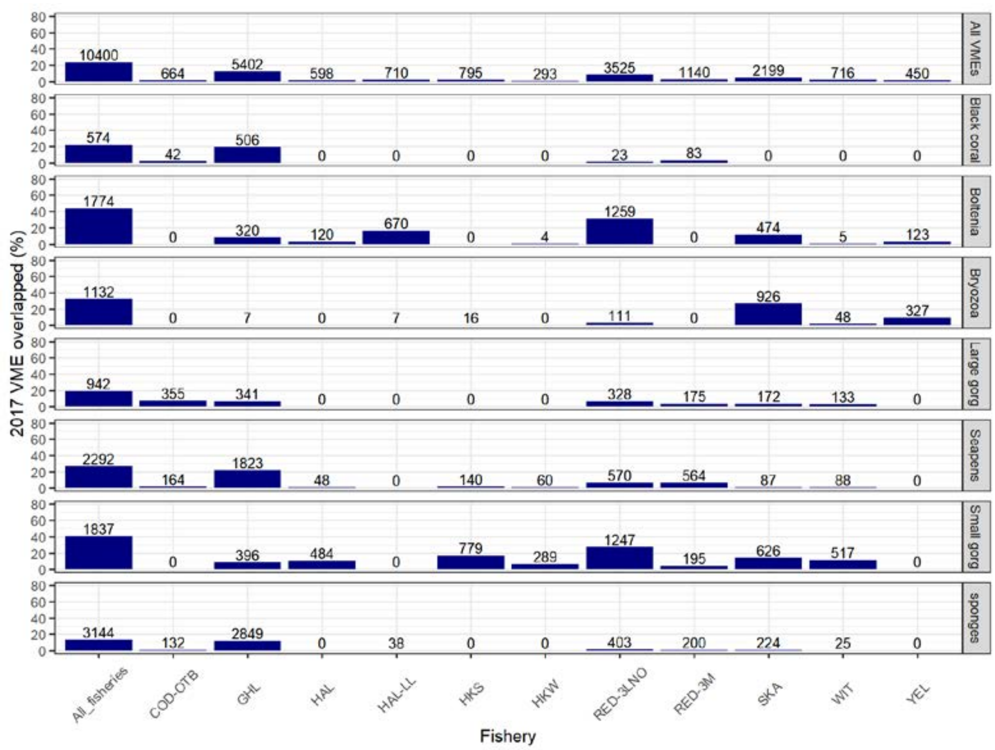


Figure 7.41. Percentage of VME polygon overlapped by cumulative fisheries (far-left bars) and fisheries-specific effort areas using the new "*Coupling VMS with Logbook*" methodology for **2017 year.**

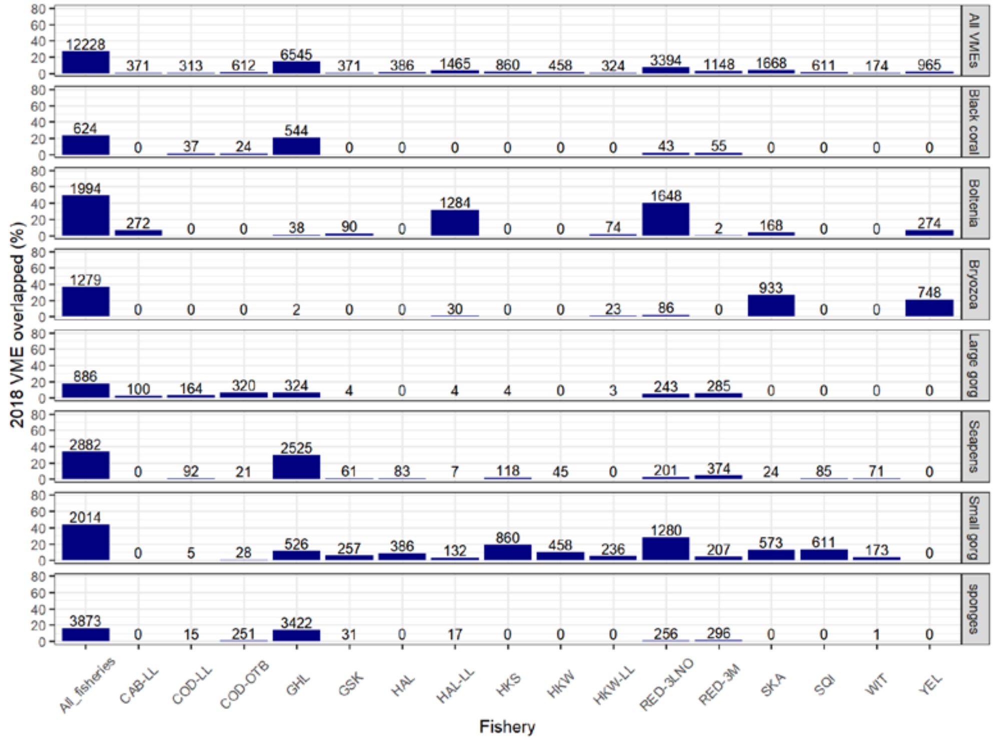


Figure 7.42. Percentage of VME polygon overlapped by cumulative fisheries (far-left bars) and fisheries-specific effort areas using the new "*Coupling VMS with Logbook*" methodology for **2018 year**.

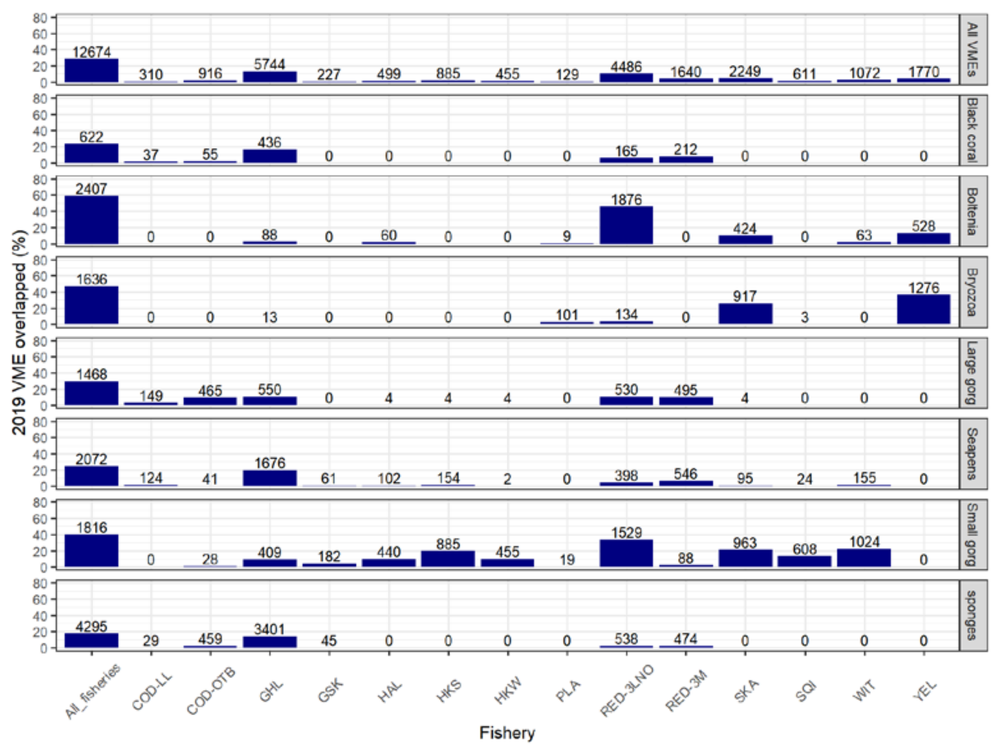


Figure 7.43. Percentage of VME polygon overlapped by cumulative fisheries (far-left bars) and fisheries-specific effort areas using the new "*Coupling VMS with Logbook*" methodology for **2019 year**.

Acknowledgements

This work was conducted as part of the NEREIDA project funded by the European Commission under Grant Agreements SI2.770786; SI2.793318 and SI2.827558.

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NAFO 2016. Report of the 9th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO SCS Doc. 16/21, Serial No N6655.

NAFO 2019. Report of the 12th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO SCS Doc. 19/25, Serial No N7027.

Assessment of Significant Adverse Impact (SAI)

i) Background to the assessment of SAI and its definition

RFMOs have made a commitment to investigate the potential for SAI as part of their response to the UNGA resolution 61/105 on sustainable fisheries (UNGA, 2006b). The resolution calls upon States and RFMO/A's to identify VMEs in the high seas and to consider whether fishing activities would have SAI on these ecosystems. One of the difficulties in assessing SAI in the NRA in the past has been the inaccessibility or lack of data of sufficient quality and resolution, both temporally and spatially, on the extent of fishing activities and of the identity and distribution of VME. Only recently have suitable datasets become available. Capitalising on the availability of such datasets, scientists in the NAFO WG-ESA have developed an approach for analysing and evaluating SAI, thus contributing to a qualitative risk assessment and management framework to avoid SAI on VME from bottom fishing activities in the NRA.

The FAO guidelines (FAO, 2009) define SAI as: "those that compromise ecosystem integrity (*i.e.*, ecosystem structure or function) in a manner that: (i) impairs the ability of affected populations to replace themselves, (ii) degrades the long-term natural productivity of habitats, and (iii) causes, on more than a temporary basis, significant loss of species richness, habitat or community types".

The guidelines (FAO, 2009) also provide further insight into the issue of defining SAI by stating that:

"When determining the scale and significance of an impact, the following six criteria should be considered:

The intensity or severity of the impact at the specific site being affected.
The spatial extent of the impact relative to the availability of the habitat type affected.
The sensitivity/vulnerability of the ecosystem to the impact.
The ability of an ecosystem to recover from harm, and the rate of such recovery.
The extent to which ecosystem functions may be altered by the impact.
The timing and duration of the impact relative to the period in which a species needs the habitat during one or more of its life-history stages."

So far, given the data available from within the NRA and specifically the NAFO footprint, the first assessment conducted by NAFO (NAFO 2015), focused on addressing the first two criteria (i and ii). **Criterion i**, the sensitivity or severity of the impact has been shown, through literature review, to be very high on the first pass through all VMEs identified by NAFO. Indeed, it is part of the determination that a taxon is a VME and was reviewed for each VME indicator previously (Fuller *et al.*, 2008; Kenchington *et al.*, 2011; Murillo *et al.*, 2011). Structural sponge habitat is extremely vulnerable to commercial and research trawling, suffering immediate declines through direct removal of sponges and further reductions in population densities of sponges due to delayed mortality (Kenchington *et al.*, 2011). Similarly, gorgonian corals are very fragile and highly susceptible to trawling impacts (Fuller *et al.*, 2008). Sea pens can also be severely impacted on the first pass, however unlike the corals and sponges, they have flexible axial rods and some species are able to re-anchor in the sediment if they are dislodged (Kenchington *et al.*, 2011). Consequently, they may be able to withstand greater disturbance than the other VME indicators, as they are less susceptible to direct mortality. The analysis described below is in agreement with these observations, where sensitivity to trawling impacts was found to be greatest in sponge, large gorgonian and black coral, while bryozoan, sea-squirts and sea pens were shown to be least sensitive.

For **criterion ii**, the location of the 7 VME types assessed in the present analysis have been mapped and the proportion of VME (as species biomass/area and functional area) impacted by fishing has been quantified. In addition, the functional and species biomass/area of VME at risk of impact, as well as the functional and species biomass/area of VME protected, has been quantified.

Criteria iii-v essentially require knowledge about the ecology of individual VME indicator species and the associated process and functions they perform. For example, ecosystem functions can be defined as the biological, geochemical and physical processes and components that take place or occur within an ecosystem. It can be divided into three categories; regulating, supporting and provisional functions. Regulating functions include processes such as biochemical and water cycling. Biochemical cycling includes processes such as benthic-pelagic coupling and bioturbation. Both contribute significantly to biochemical cycles by turning over nutrients, living or decomposed constituents, in an otherwise nutrient poor environment. Supporting functions include the provision of habitat for associated species, nurseries, refuge from predators, and supporting connectivity between populations (*e.g.,* patchiness). Specifically, within the NRA, sponge grounds provide a number of ecosystem services. For example, they stand proud of the sea floor, and modify bottom currents which creates habitat for other species. In addition, fish use sponge grounds for feeding, reproduction and resting, while sponges filter vast amounts of water daily (one sponge can filter 25 000 litres per day) and serve broader roles in energy flow linking pelagic and benthic systems and locally increasing biodiversity. At some unknown size and spatial configuration, these ecosystem services will be compromised, and each function may have a different ecological tipping point. Further, recovery of these disrupted ecosystem functions and services not only requires knowledge of the life-history of the key species, it requires a thorough understanding of the entire benthic community and the successional processes that occur. Ecosystems have a degree of functional redundancy in them and it could be that some functions are maintained by non-VME indicator species. Knowledge of the degree to which fishing can proceed without compromising ecosystem services is an extremely important question that will require a targeted research program over several years in order to fully address. Lastly, **criterion vi** is mainly related to species which temporarily utilise VME habitat at some point during their life histories. This can best be ensured by successfully addressing criteria iii – v and ensuring that the habitat is protected from SAI.

WG-ESA initiated the discussion of how to assess SAI at two basic levels:

i. Assume that any present or past fishing activity impacting VME is significant based on the Precautionary Approach; or

ii. Assume that the present or past fishing activity impacting VME may not be significant as both VME and fishing have co-existed for several decades.

The first scenario was thought, by some, to be applicable to the sponges and large gorgonian corals, but not to the sea pens. The argument for not including sea pens under this scenario was based on their relative resilience at the species level to trawling, as noted above. However, in situ photographs of the sea floor within a heavily fished portion of a sea pen VME polygon showed no megafauna, despite the presence of sea pens in the nearby closed area, indicating that sea pens cannot withstand concentrated and repeated fishing effort. Furthermore, WG-ESA previously noted that redfish larvae attach to the sea pen stalks and these habitats may be important nursery areas for *Sebastes* spp. (see ToR 3.1.2 of NAFO 2014), thereby increasing the risk to NAFO fisheries should too much sea pen habitat be destroyed. WG-ESA at its 2013 meeting assessed the protection of sea pens on Northern and North-western Flemish Cap to be "Inadequate collectively" based on the fact that the closures are covering a system of sea pen VME, identified in the SDM and verified with trawl survey data, that is not adequately protected. In particular, the lack of protection for the entire eastern part of their distribution was of concern for the long-term sustainability of these VME given the lack of knowledge of recruitment processes and connectivity. Therefore, although they may be more resilient to a first pass of the trawl gear than other types of coral or sponge, sea pens have more of their core VME area unprotected.

This discussion also raised the point of the need to take into account the impact to individual VME polygons as some VME areas may be severely impacted by fishing, while others may not be impacted at all. This could lead to the loss of individual patches of VME which could have consequences for other areas of the same VME type depending on source/sink relationships.

The second scenario has some logic to it. Fishing has persisted in these areas for many years and previously WG-ESA has shown that the areas fished have been remarkably consistent (NAFO, SCS Doc. 15/19). The directed Greenland halibut fishery, that is the main fishery carried out in waters below 700 m depth (Gonzalez-Costas et al., 2011), where the sponge VME occur, began in the early-1960s in this area (Bowering and Brodie, 1995), indicating that impacts of fishing on the sponge VME may have been accumulating for at least 50 years. Therefore, if the current extent and impact of fishing had caused SAI then we would expect to see consequences either to the fisheries or to the VME indicators. A review of existing *in situ* imagery to assess size distribution and recruitment of VME indicators could give some insight into this issue, and/or targeted *in situ* monitoring could be conducted. Until research vessel surveys cease to fish in the closed areas, they could be tasked with recording the length frequencies of all VME indicator taxa within the VME polygons.

However, an important consideration for assessing SAI and highlighted in the FAO guidelines, is the need to determine the area of VME impacted as a proportion of the area of VME unimpacted. Studies in other marine ecosystems, in the context of the EU Habitat Directive, had considered that impacts of 25% or more of the total habitat area as the criteria for deeming those habitats to be in unfavorable conditions (Korpinen and Laamanen, 2013). Therefore, by definition, if 76% of the habitat were protected, it would be in favorable condition. This then introduces two fundamental ways of assessing SAI, namely; **i.** from the perspective of protecting habitat and thereby limiting the **risk of future SAI occurring**, and **ii.** from the perspective of quantifying the impacts of bottom fishing activities and thereby determining if **SAI has occurred**. Of course, we have high uncertainty and limited ways of assessing the historic distribution of VMEs, so what may be 76% of a habitat protected at the present time, would likely be much less if the historic distribution and loss of the habitat were considered. Therefore, both approaches are required to fully assess SAI, but it is perhaps with greater immediate certainty and absolute quantification for management purposes that protecting significant areas of VME habitat and biomass (as in the example above) will reduce the risk of impact and potential SAI occurring, while investigations are on-going to quantify the 'actual' impacts of bottom fishing activities with respect to SAI.

WG-ESA therefore concludes that not all impacts on VME should be presumed to be SAI. Furthermore, while an assessment of the relative area/biomass of VMEs **impacted** with area/biomass of VMEs of the same type at **risk of impact,** is an important step in assessing SAI, they both need to be evaluated with respect to the proportion of VME **protected**. Then then represents the general approach we have taken to assess SAI in the present study.

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ii) VME impacts, resilience, and recovery: a review

Impacts

Fishing impacts on VMEs can involve both i) the physical contact between the fishing gear and the VME species and ii) and increased sediment turbidity in the water column due to contact between the gear and the seafloor. In the case of physical contact, impacts can result from either VME damage or removal. For sessile taxa, dislodgement caused by contact with fishing gear will likely lead to damage followed by death, as they are not able to relocate. Corals such as large gorgonians are often found directly attached to hard substrate (*e.g.*, boulders, cobbles) and their fragile skeletons might not resist mechanical contact. In the case of small gorgonians living directly on soft substrate (*e.g.*, *Acanella arbuscula*), dislodgement will also potentially imply in their demise, as they are not capable of upturning themselves if dislodged by the gear. Sea pens, most of which also live directly on soft substrate, are considered capable of a certain degree of movement, and in some cases can relocate and uproot themselves back in the sediment if dislodged, which has been reported for *Funiculina quadrangularis, Pennatula phosphorea,* and *Halipteris willemoesi* (Eno *et al.*, 2001, Malecha & Stone, 2009). However, increased predation and a high mortality rate were also observed in the case of *H. willemoesi* colonies (Malecha and Stone 2009).

Sea pens have also been considered more resilient because some species can withdraw into the sediment. It has been suggested that species such as *Pennatula aculeata* can take advantage of this behavior and partially escape trawling (Benoît *et al.*, 2020). However, *P. aculeata* is one of the sea pen species with the highest bycatch biomass from scientific trawl surveys in the Newfoundland Region (Rideaout *et al.* in review), which indicates that their ability to escape from trawls might not be reliable. In *Pennatula rubra*, withdrawing is a slow process that can take up to three minutes (Chimienti *et al.*, 2018). Furthermore, cues that lead to withdrawing behavior in sea pens are not yet well understood (Langton *et al.*, 1990; Ambroso *et al.*, 2013). Finally, this behavior is not widespread among sea pen species found in the NRA; for instance, neither *Anthoptilum grandiflorum* nor *Halipteris* spp. are capable of it.

In the case of removal, impacts are likely more substantial, although there is no available data on proportion of caught-retained *versus* damaged-but-not-caught specimens. One of the clear consequences of VME species removal is habitat loss (Watling and Norse 1998). Sea pens have been suggested to have a role as habitat for Redfish larvae (*Sebastes* sp.); eggs or larvae of the lantern fish (*Benthosema glaciale*) and the eelpout (*Lycodes esmarkii*) were also found associated with sea pen colonies (Baillon *et al.*, 2012). Because sea pens create heterogeneity in areas of flat bottoms, their role as habitat for other species in these environments might be particularly important. In certain areas, their removal might have implications for the health of species that might use or depend on them. Other corals and sponges have been shown to provide habitat for other species (Moore *et al.*, 2008; Le Guilloux *et al.*, 2010; Beazley *et al.*, 2013, 2015; Kutti *et al.*, 2014; Milligan *et al.*, 2016; Gates *et al.*, 2017; Neves *et al.*, 2020) and to play a role in geochemical cycles and to increase sediment infauna diversity (Cathalot *et al.*, 2015; Pierrejean *et al.*, 2020).

Sediment disturbance from commercial trawling can be long-lasting and have large spatial extents, although this will depend on several factors including local oceanographic regimes, water depth, bottom type, and gear type and dimensions (Martín *et al.*, 2014). In some cases, sediment clouds produced during bottom trawling can be a few meters in height (*e.g.*, 3-6) and dozens of meters in width (70-200) (*e.g.* Durrieu De Madron *et al.*, 2005). However, the impact of sediment clouds on VMEs has not been particularly studied. It is expected that high sediment turbidity might clog coral polyps and interfere with sponge physiology (Tompkins-Macdonald and Leys 2008; Bell *et al.*, 2015). The sea pens *P. phosphorea*, *F. quadrangularis* and *Virgularia mirabilis* recovered from experimental smothering resulting from experimental shrimp creel deployments, when exposed for 24-48 hours (Eno *et al.*, 2001). However, the effects of turbidity generated by creel deployments might not be comparable to those generated from bottom trawling. Of relevance is the fact that sediment clouds generated from bottom trawling taking place outside of fisheries closures might be capable of reaching and affecting fauna living inside of closures. Grant *et al.*, (2019) showed that sediment clouds produced during bottom trawling activities taking place outside of a conservation area in British Columbia (Pacific Canada) had an impact on glass sponges found at >2 km from the source, inside the conservation area.

Resilience and recovery

One of the FAO criteria used to consider a marine taxon as vulnerable to fisheries is their potential for high longevity and slow growth rates (FAO, 2009). Slow growth rates and high longevity of some deep-sea corals have been considered at the time they were identified as VME indicators (Fuller *et al.*, 2008). Taxa longevity has been shown to be a factor influencing recovery in benthic organisms subject to trawling disturbance. Hiddink *et al.* (2019) found that recovery rates in benthic organisms with longevities >10 years were more affected than less long-lived fauna (*i.e.*, 1–3 years) exposed to bottom trawling. Longevity and growth rates have been estimated for a few sea pen taxa, all studies indicating comparable longevities in the order of decades (Neves *et al.*, 2015b, 2018a; Murillo *et al.*, 2018), and in the order of decades to centuries for gorgonians (Sherwood and Edinger 2009). Although growth rate ranges are comparable within functional groups, they might vary across taxa. For instance, average linear growth rates of feather-like sea pens such as *Pennatula aculeata*, *Anthoptilum grandiflorum* (Murillo *et al.*, 2018) and *Pennatula grandis* (Neves 2016) seem to be slower than those of whip-like taxa such as *Halipteris* spp. (Wilson *et al.*, 2002; Neves *et al.*, 2015b) and *Umbellula encrinus* (Neves *et al.*, 2018b). Longevity of other VME indicators such as sponges, crinoids and bryozoans is more limited. Some crinoids have been estimated to live up to >20 years and different species have been shown to have different growth strategies and rates (*e.g.* Messing *et al.*, 2007). The sparse published literature on cold-water sponge growth and longevity indicates that some sponges can live up to 440 years (Fallon *et al.*, 2010). In the case of *Boltenia ovifera*, estimates based on shallow-water populations indicate that they might live for at least three years (Plough 1969). Often the lack of skeletal structures that can be used for ageing limits these types of study for some of these organisms. The limited information on growth rates and longevities for these VME indicators had already been acknowledged by Murillo *et al.* (2011), and since then no additional information has become available.

Knowledge of reproductive characteristics is also important to better understand resilience and the potential for recovery in VME indicators. Baillon *et al.* (2015) compared published information on reproduction traits of deep-water sea pens, and showed that in most known cases, they are dioicious and broadcast spawners. While in many cases sea pens produce gametes year-long, peak in production and release is often seasonal, and thought to be a response to phytoplankton bloom cues (Baillon *et al.*, 2015). The large gorgonians *Primnoa resedaeformis* and *Keratoisis ornata*, also found in the NRA, are also broadcast spawners with external fertilization (Mercier and Hamel 2011). *K. ornata* also shows seasonality patterns, with spawning taking place in late summer. On the other hand, no evidence of reproductive periodicity was identified in examined colonies of *P. reseadaefomis*, which seems to have a year-long gametogenic cycle, although authors highlighted the potential for confounding effects with depth (Mercier and Hamel 2011). There is limited information on size-at reproduction for most coral and sponge species found in the NRA. Colonies of *H. finmarchica* 10 cm in height were shown to bear gametes (Baillon *et al.*, 2015), but in *A. grandiflorum* size at maturity was estimated at 24 cm (Baillon *et al.*, 2014). In the small gorgonian *Acanella arbuscula*, colonies as small as 3 cm in height already contained gametes, although one colony 7 cm in height without gametes was also found (Beazley and Kenchington 2012), which suggests that their absence should not be interpreted as an absolute indication of non-reproductive status in colonies of this species. Assexual reproduction has rarely been reported for cold-water coral taxa. But recently, Rakka *et al.* (2019) revealed a previously unknown polyp bailout behavior in both *A. arbuscula* and *Acanthogorgia armata* (also small gorgonian). Polyp bailout is considered a development activity in which intact polyps detach from the mother colony under stress conditions, to initiate a new colony, characterizing an asexual method of reproduction. Polyp bailout has also been recently reported in *Antipathella subpinnata*, a mesophotic black coral species (Coppari *et al.*, 2020).

Information on larval biology and early development in VME indicators is also limited. In some cases, larvae characteristics have been inferred based on other evidence; for instance, development of lecithotrophic larvae have been suggested for some sea pens based on large oocyte sizes (*e.g.* Baillon *et al.*, 2014, 2015). Whether larvae are lecithotrophic or planktontrophic has implications in terms of their duration in the water column, and therefore on their susceptibility to predation as well as dispersal potential. In *F. quadrangularis* it has been suggested that the high gene flow observed between colonies found in two Scottish sea lochs might be due to its lecithotrophic larval stage (Wright *et al.*, 2015). The sea squirt *B. ovifera* has been shown to spawn in the winter and to produce lecithotrophic larvae, which metamorphose into zooids over a period of 24-36 h, although feeding zooids were only collected at least one month after spawning. Importantly, young zooids have been commonly found on the stalks of adults (Lacalli 1981).

In the case of sponges, they reproduce by broadcasting sperm into the water column which fertilize eggs held in the bodies of neighbouring sponges. If sponges are too far apart then fertilization success may be compromised. An extinction vortex is the term used to describe the process that declining populations undergo when a mutual reinforcement occurs among biotic and abiotic processes that drives population size downward to extinction. Sponges, corals and sea pens, which also have broadcast spawning, may be vulnerable to extinction vortices. The sponges also may have very limited dispersal ability. The fertilized egg usually develops in the sponge and on hatching, larvae are released into the water column where they are only viable for a few days, and in some species, only hours. They then settle and attach. This could mean that the sponges are highly inbred and have very limited dispersal range. If this is the case greater importance is placed on each self-recruiting population. Alternative models include source-sink dynamics, where one or more populations provide the recruitment for other populations and clinal variation, where genetic variation follows the distribution gradient. Each model has different implications for management and very little is known about the population genetics and connectivity of these species.

Scarce knowledge on growth rates, longevities, the duration of larval pelagic stage, larval survival rates, success of larvae settlement, and colony/individual early growth limit our understanding of the potential for individual and population-level recovery of VME indicators. However, in the lack of a complete suite of information on specific taxa, composite information on related taxa has been used as proxies to model the potential for recovery. Modeling based on sea pen biomass accumulation curves has been conducted by WG-ESA to estimate sea pen resilience and recovery (NAFO 2016, 2018, 2019). The importance of considering different variables in these exercises (*e.g.,* different vessel speeds and gear width) and data resolution (*e.g.,* VMS data) has been highlighted, as biomass accumulation curves can significantly differ depending on the variants applied (*e.g.,* which vessel speed). Depending on which variants were used, sea pen biomass in the NRA had been estimated to recover to 50% of pre-impact values in 3.9 to 11.6 years (NAFO, 2018). However, the more recent modelling produced by WG-ESA using more accurate spatial data indicates that recovery times are likely to be longer than previously estimated (NAFO, 2019). Although these models provide useful information on potential for recovery at the population level, rather than at the individual level, the consequences of VME species removal on ecosystem dynamics have not yet been assessed. Therefore, recovery in terms of biomass might not necessarily signify immediate functional recovery (*e.g.* Barrio Froján *et al.*, 2011).

Additional modelling focused on VME recovery conducted by WG-ESA includes the development of an Agent-based Model (ABM) for sea pens in the Newfoundland-Labrador and Flemish Cap bioregions, as a tool to evaluate the impacts of fishing and the effectiveness of closures (NAFO 2019). The AMB uses abundance data, rather than biomass, and it simulates the spatio-temporal dynamics in the life-history of a generalized sea pen species, including colonization, responses to perturbations, and the effectiveness of closures as a mechanism to promote recovery (NAFO 2019). This ABM has highlighted that recovery time varies across closures, with closure size, location, and depletion level being important determinants of effectiveness. For instance, several NAFO sea pen closures seem to be too small to allow for recovery. The model has identified that in the absence of fishing, recovery of an area could take place in 50 years (considering NAFO closures in areas estimated to have been depleted at 60% of sea pen abundance). On the other hand, under the current fishing scenarios sea pen connectivity might be compromised, leading to longer recovery times. In the case of the NAFO closures, this recovery time can exceed 100 years, although individual closures can recover in up to 15-25 years (NAFO 2019).

The ABM has been applied to sea pens, but no similar models have been generated for other VME taxa. ABM uses data on abundance, which can be challenging to obtain from trawl surveys, particularly for taxa that are often collected fragmented, such as large gorgonians and many sponge taxa. Instead, recovery of large gorgonians and other VME indicators can be assessed by examining the presence of recruits and temporal shifts in abundance from imagery data. Bennecke and Metaxas (2017) identified higher coral abundance, the presence of large colonies, and recruits, when comparing data from before and after a fishing closure's establishment in the Gulf of Maine (2001 vs. 2006), which has been interpreted as signs of recovery. In their review of potential recovery of benthic communities in seamounts, Goode *et al.* (2020) found that benthic communities can recover once protection measures are put in place. As it would be expected, recovery status and level (*e.g.,* no recovery, intermediate, or high recovery) is taxa-dependent. From the perspective of VME indicators, these authors found that most corals (alcyonaceans, small and large gorgonians, and scleractinians) exhibited no recovery, while sea pens, ascidians, bryozoans, and stalked crinoids all exhibited low recovery. Noticeably, for some seamounts, stalked crinoids and sea pens only showed significant positive recovery after 30 years of closure. These authors also found that certain taxa which have been hypothesized as having high recovery potential (*e.g.,* including crabs, holothurians, echinoids, and pagurids) exhibited no or low recovery. Recovery has been shown to be possible within decades of protection (*e.g.* Baco *et al.*, 2019; reviewed in Goode *et al.*, 2020). However, little is known about pre-fishing historical levels. The bamboo coral forest in SE Baffin Bay has been shown to exist for at least 2 000 years (Edinger *et al.*, 2017), and sponge grounds have been colonizing areas in the Flemish Cap and Grand Bank for >130 ka BP (Murillo *et al.*, 2016). In the case of the bamboo coral forest, which has been trawled in the past, no visible signs of recovery have been detected yet (Neves *et al.*, 2015a).

The impact of trawling on ecosystem dynamics and ecological interactions might be significant, and it has not been widely assessed. For instance, successful growth of sea star populations that could potentially predate on juvenile sea pens would be expected to have implications on sea pen population dynamics. Furthermore, information on early growth and fitness of cold-water coral and sponge species is scarce. Community succession will be affected in areas where fishing still takes place. Persistent trawling can lead to more homogeneous communities as a result of community succession 're-starts', as a result of unsuccessful recovery attempts (Clark *et al.*, 2019). Shifts in benthic communities as a result of natural disturbance provide a good example on the importance of succession considerations. Teixido *et al.* (2004) estimated faunal recolonization to begin within 10 years after disturbance following iceberg scours in Antarctica. In another example, Antarctic benthic communities subject to the impacts of sediment runoff linked to glacier retreat - resulting from climate change - have shifted from communities dominated by filter feeders and ascidians to a mixed assemblage dominated by sponges and the sea pen *Malacobelemnon daytoni* across 16 years (Sahade *et al.*, 2015).

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iii) VME area/biomass impacted and at risk of impact: methodological approach.

The overall methodology applied to assess VME biomass and VME area impacted, including the risk of impact, follows the same methodological approach as applied in the first SAI assessment in 2015 (NAFO SCS doc.15/19). Although some steps in the present analysis utilised some updated methods, the assumptions made in the 1st assessment also apply to the updated analysis. These are: (1) all significant concentrations of VME are located within the defined VME polygons, (2) the risk of impact to VME from fishing inside either closed areas or in areas outside the fishing footprint is deemed to be negligible and these areas are regarded as 'protected' for the purposes of the SAI assessment, (3) VME which occur outside closed areas, but within the fishing footprint, are at risk of impact from bottom fishing activities, and (4) the degree of risk of impact will depend upon the combination of the fishing intensity and the VME biomass concentration and extent.

Given such assumptions, the following assertion can be made: frequently fished areas of VME habitat will tend to have a lower biomass of VME indicator taxa compared to areas of the same VME type that have been fished less frequently. This assumption presents two alternative hypotheses, which can be tested: (i) areas at risk of SAI are those areas defined as VME (outside of VME closed areas) but within the active fishing footprint that are subject to a relatively low fishing pressure, and (ii) areas defined as VME where an impact (possibly a SAI) has already occurred (outside of VME closed areas) that have been subject to a relatively high fishing pressure over many years, and where VME indicator taxa are unlikely to be found in significant concentrations. The challenge, therefore, is how to identify the boundary between areas of VME at risk of SAI from the areas of VME that have already sustained an impact (possibly a SAI). Figure 7.44 illustrates the approach taken to overcome this challenge.

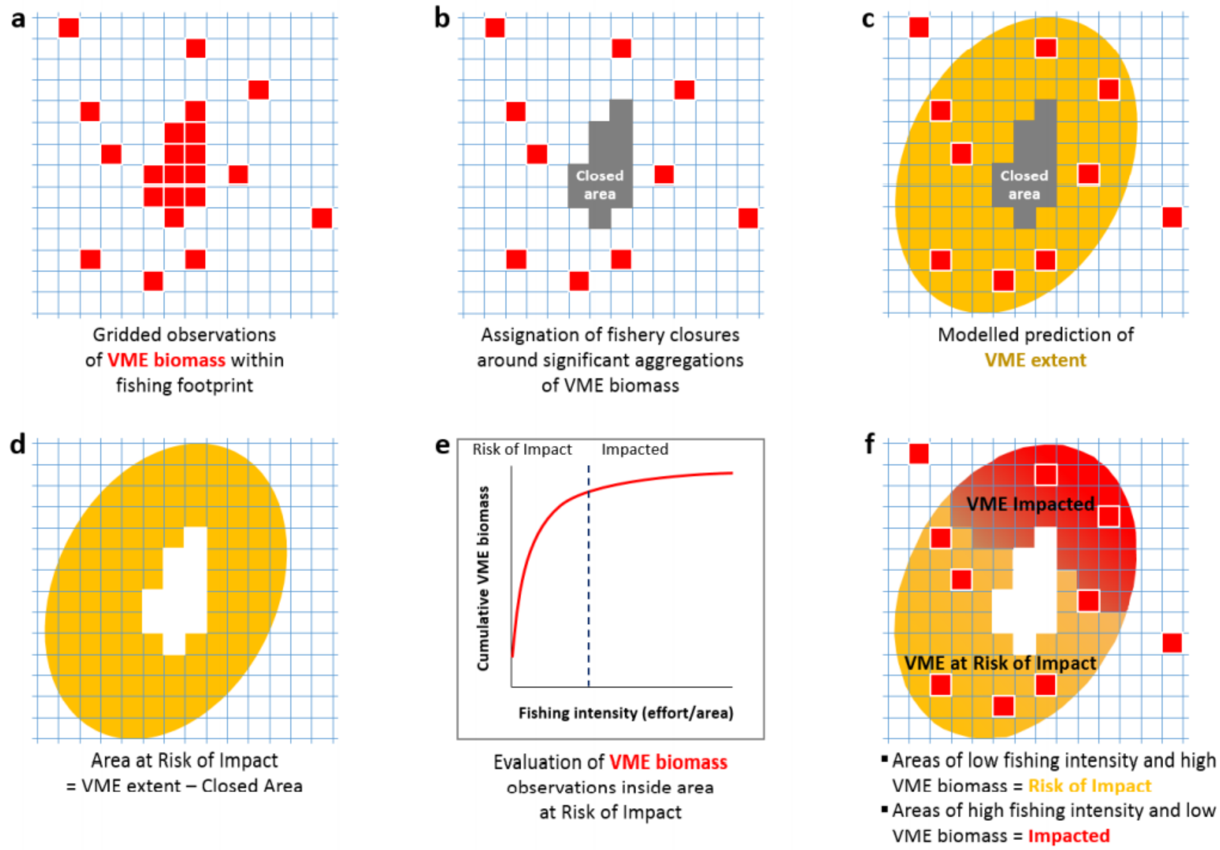

Figure 7.44. Generalised description of the analysis framework for assessing the proportion of VME biomass, protected, impacted and at risk of impact. **A**, significant concentrations of VME indicator species are gridded/mapped; **B,** areas which constitute the highest concentrations of biomass are subject to bottom fishery closures in consultation with fishery managers; **C,** VME polygon areas are defined using KDE analysis which are typically larger than the closed areas as they encompass adjacent significant concentrations of VME and VME habitat; **D,** the area of VME at risk of impact is therefore the VME polygon area which excludes the protected closed area; **E,** the interaction between fishing intensity per grid cell and VME biomass per grid cell can now be assessed, to attempt to distinguish areas of VME most at risk of SAI from areas of VME impacted. This is achieved by ranking every grid cell within the VME polygon area on a gradient of increasing fishing intensity and plotting the observed VME biomass along that gradient, a rate of increase in the cumulative VME biomass with increasing fishing intensity can be produced to define a depletion function in response to bottom trawling. The point at which the addition of grid cells with higher fishing intensity no longer corresponds with a significant increase in VME biomass denotes a threshold (or cut-off value) in fishing intensity above which a sustained impact has occurred; **F,** Grid cells falling below the threshold, which continue to yield high biomass at very low levels of fishing intensity can be considered at being at risk of impact, both areas of impact and risk of impact can be mapped and monitored overt time using the fishing intensity cut-off value applied to the fishing effort data.

VME extent in the current analysis is based on the updated VME polygons produced by Kenchington *et al.* (2019) using kernel density estimation analyses (KDE). The 2019 VME polygons include updated versions of the estimated extents of sponges, large gorgonians and sea pens used in the 2015 analysis, and the new polygons for small gorgonians, *Boltenia* sp. ascidians, bryozoans and black corals. The spatial distribution of VME biomass inside the VME polygon boundaries is represented in a 1 km grid averaging observed biomass in each grid cell, and interpolating biomass for cells without sample data. The biomass grid approach is described in detail in (Section 7b)iii).

The area of potential fishing impact is delineated using the fishing footprint, a perimeter boundary containing all bottom fishing activity within the NRA between 1987-2007 (NAFO, 2009c). The fishing footprint borders the Canadian EEZ in the west, while off the shelf it is mainly restricted to a depth no greater than 1600 m. The distribution of fishing effort, and hence potential impact, is mapped utilising the same 1 km grid as the VME biomass, and 10 years (2010-2019) of fishing activity data derived from the Vessel Monitoring System (VMS), which transmits vessels' position, heading and speed every hour.

Areas of VME, as represented by the KDE polygons, are divided into three impact-risk categories:

(i) **'protected'** areas with low risk of impact, including fisheries closures and areas outside of the NAFO fishing footprint boundary;
(ii) areas **at 'high risk' of impact** (and therefore subject to potential SAI) which are currently subject to low or no fishing pressure, but are open to fishing within the fishing footprint;
(iii) areas that are **'impacted'**, which coincide with areas of high fishing effort occurring over many years, and where VME habitat and indicator taxa are found with much reduced biomass.

The definition of high fishing effort, leading to an impacted state, is linked to observed large changes in VME species biomass. The method used to determine cut-off values representing high fishing effort uses the cumulative distribution of biomass catch in conjunction with fishing effort (VMS) data as depicted and explained in Figure 7.44. In a departure from the methodology used in the 2015 assessment, in which the accumulation of biomass over ranked fishing effort used the 5 km gridded biomass layer and the corresponding average fishing intensity per biomass grid cell, the new analysis links biomass observed in each scientific trawl to the fishing intensity in the area immediately surrounding the trawl. While VME inside existing fisheries closures, and in areas outside the fishing footprint are classified as 'protected', areas within the fishing footprint are classified as impacted or at risk of impact according to the VME-specific fishing effort cut-off values applied to the fishing effort distribution layer. The proportion of VME area and biomass in each impact class is calculated in a GIS overlay analysis of the VME boundary, biomass layer and impact class layer, all sampled using the same 1 km grid. Figure 7.45 outlines individual steps in the assessment of the VME biomass and VME area which is, i. protected, ii. impacted and iii. at risk of impact, which are described in the following report sections.

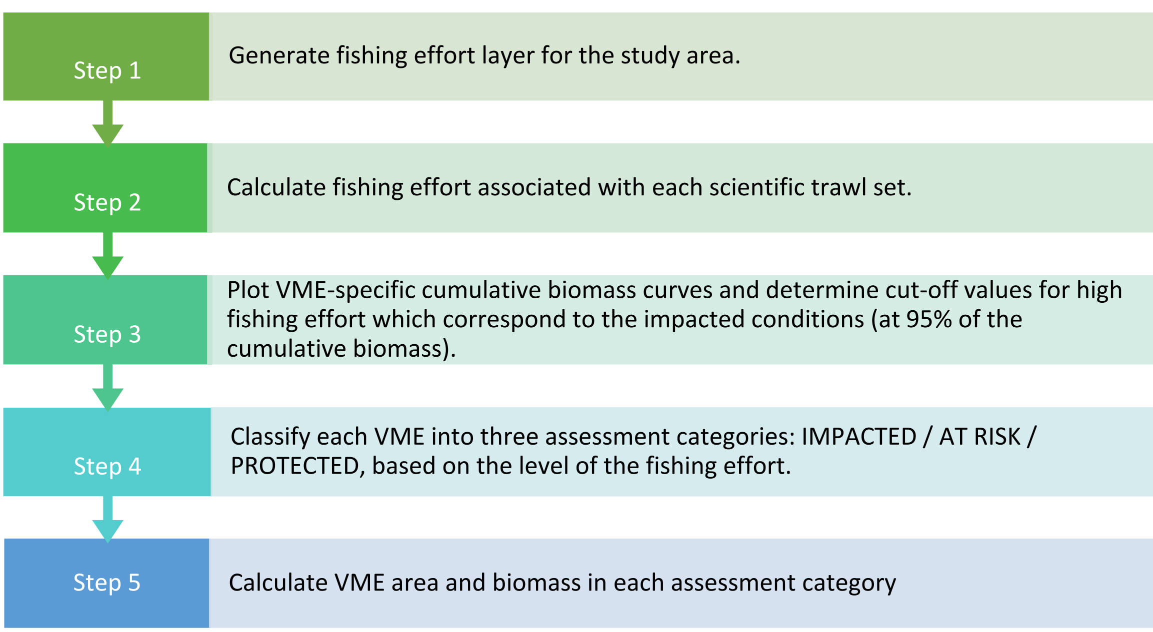

Figure 7.45. Analysis steps to quantify VME biomass and area impacted, at risk of impact and protected.

iv) Overlap of demersal fisheries with VMEs

Fishing effort calculation (Step 1)

Fishing effort in the present assessment is calculated as kilometres (*km*) of trawl track travelled by a fishing vessel per km^2, per year (NAFO SCS doc. 19/25), which differs from that used in the 2015 assessment, where fishing effort was enumerated in hours per km^2. Vessels fishing in the NRA all transmit their position, heading and speed every hour via their VMS. Each transmission is termed a 'ping'. The point locations of VMS pings by individual vessels collected between 2010 - 2019 were filtered to speeds between 0.5 - 5 knots, based on known fishing speeds derived from log-book data, and converted into line features by the NAFO Secretariat using the methodology described in (NAFO SCS doc. 19/25). Each line feature is therefore assumed to represent the path travelled by the vessel while fishing. In addition, each line was attributed with the type of fishing gear used by the vessel.

The benefit of using the VMS tracks instead of raw pings is in accounting for the ship's trajectory between pings, allowing a more spatially resolved accumulation of effort which can be spatially linked with the VME indicator species biomass records more precisely. Figure 7.46 illustrates the improved delineation of areas with fishing effort resulting from the finer spatial resolution achieved using track lines *vs.* pings. In areas such as the NRA, where most bottom trawling follows bathymetric contours, there can be sharp transitions from fished to unfished areas, that are much better represented by the finer resolution mapping of VMS derived trawl track line densities.

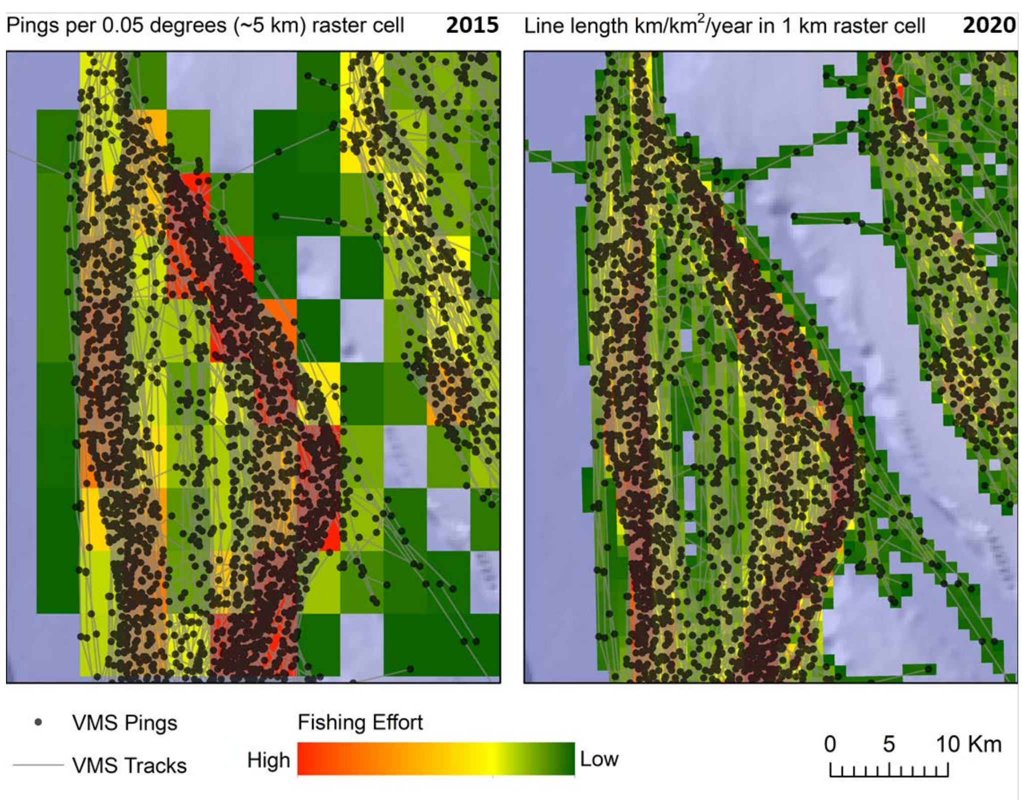

Figure 7.46. Comparison of spatial resolution of fishing effort layers derived from VMS pings and trawl tracks showing the grid resolution of 5 km used in the first assessment (left panel) and the higher grid resolution of 1km applied in the present assessment (right panel).

VMS tracks resulting from trawlers and long-liners were treated separately. The main impact to the seafloor is considered to come from the bottom-trawl fisheries. Consequently, the fishing effort layer used in further analyses included bottom-trawl fisheries only. A separate raster grid was produced for fishing effort from long-line fisheries for comparison.

The effort layer was produced using a moving window approach. The total length of VMS track within a specified neighbourhood was calculated using the ArcGIS Spatial Analyst 'Line Statistics' tool (ArcGIS 10.5). The cell size for the output raster layer was specified as 1 000 m and it was constrained to the same grid used for the VME biomass layers included in the SAI analysis. Radius of the circular neighbourhood was set at 565m, which corresponds to an area of 1 km^2. The line length (in metres) within the specified neighbourhood for each raster cell was converted to the unit of *km/km²/year* by first converting metres into kilometres and dividing the line length by the number of years of data (10 yrs.) included in the VMS tracks line feature. The final output raster layer of fishing effort calculated from VMS tracks for the trawl fisheries are shown in Figure 7.47

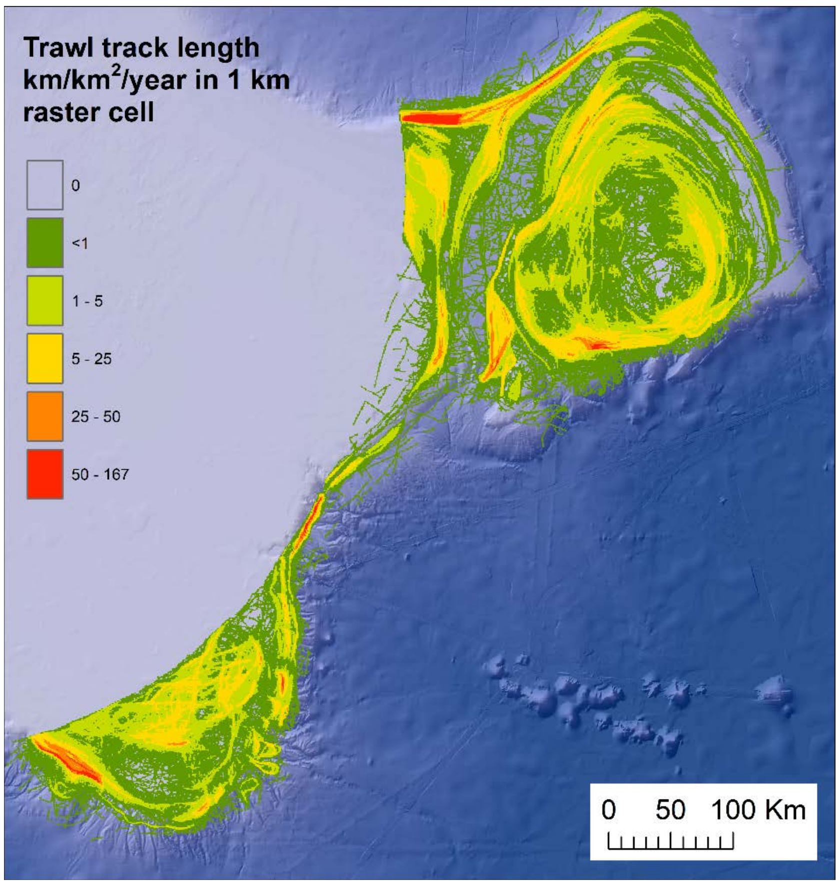

Figure 7.47. Distribution of effort from trawl fisheries in the NRA between 2010 - 2019 at the 1 km resolution as used in the present assessment of SAI.

v) Cumulative VME biomass curves

Scientific trawl data (Step 2)

Biomass data for the seven VME indicator taxa (black corals, *Boltenia* sp. ascidians, bryozoans, large gorgonians, small gorgonians, sea pens and sponges) was obtained from scientific trawls collected in the NRA in annual fishery surveys between 2011 and 2019 by Canada (DFO) and the European Union (Spain and Portugal). For this analysis, all scientific trawls were plotted as lines in GIS using their start and end coordinates. On account of the short duration of survey tows (15 – 30 minutes), lines in excess of 10 km in length were excluded from the dataset to exclude tows with potentially incorrect coordinates. Scientific trawls acquired before 2011 were excluded from the analysis to allow for at least one year of VMS data to precede the tows.

Fishing effort associated with scientific trawls (Step 2)

In the 2015 SAI analysis (the first assessment), the fishing effort associated with each scientific trawl for plotting biomass curves was extracted from a 5 km grid of fishing effort (hrs./yr./km^2) by intersecting the start point of the trawl with the grid. As illustrated in Figure 7.48, the effort value assigned to each scientific trawl from the 5 km grid may not accurately represent the actual effort. Consequently, in the current analysis effort was estimated in a defined buffer area around each scientific trawl, established by buffering the trawl line to 500 m in all directions (Figure 7.48). These buffer areas are what constitute each sample area and are referred to as such in the following text. Fishing effort was calculated by summing the line length of VMS tracks from 2010 - 2019 falling inside each sample area and dividing the total length of line in *km* by its surface area in *km*^{2}. Finally, the total length by area was divided by the number of years in the track dataset (10 yrs.) to derive the metric *km/km*^{2}*/year*. The new methodology associating the scientific trawl biomass directly to fishing effort in its immediate surrounding area, gives a much more accurate estimate of the fishing effort associated with each sample biomass.

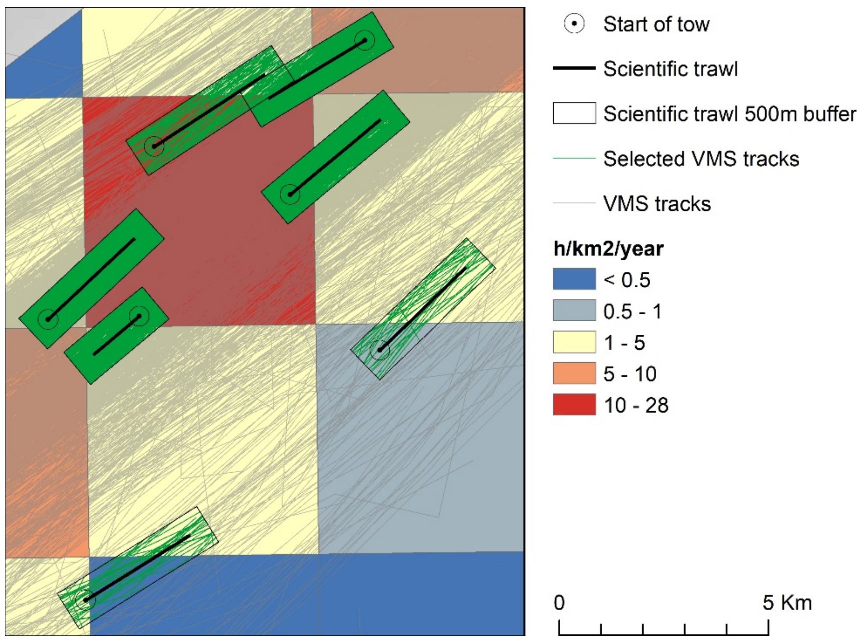

Figure 7.48. An example of actual data showing the 5 km^2 fishing effort layer as used in 2015 with cumulative VMS lines crossing the area. In the present assessment 500 m buffers are placed around the scientific tow track to sample the VMS lines (in green) which represents the most likely effort associated with each scientific tow. This creates a more spatially accurate correspondence between the fishing effort and the survey trawl biomass values.

With the scientific trawls covering an average distance of between 2 - 3 km, it is inevitable that some will traverse between areas of high and low VMS track density (Figure 7.49a, Figure 7.492b), resulting in only part of a scientific trawl corresponding to high fishing effort. VME biomass is inherently patchy, and the scientific trawls are assumed to incorporate that patchiness over the survey trawl sample area. This also includes survey trawls which are only partially heavily impacted, as shown in Figure b. For example, a scientific trawl which traverses an area from no fishing effort to high fishing effort may have a similar estimate of overall fishing effort to a scientific trawl conducted in a less intensively, but consistently fished location. The patchiness of VME may lead to high catches in such trawls from the unfished part of the scientific trawl sample area. To take account of this gradient in fishing effort within the scientific trawl sample areas, biomass records corresponding to a mean annual associated fishing effort > 1.1 *km/km*^{2}*/year* where the sample area covered by 95% of track lines is < 90% of the total sample area were considered as unrepresentative and excluded from the analysis (Figure 7.49c). Most sample areas have an even distribution of VMS tracks across the whole sample area and therefore relatively few (≤ 4%) samples were excluded from the data set.

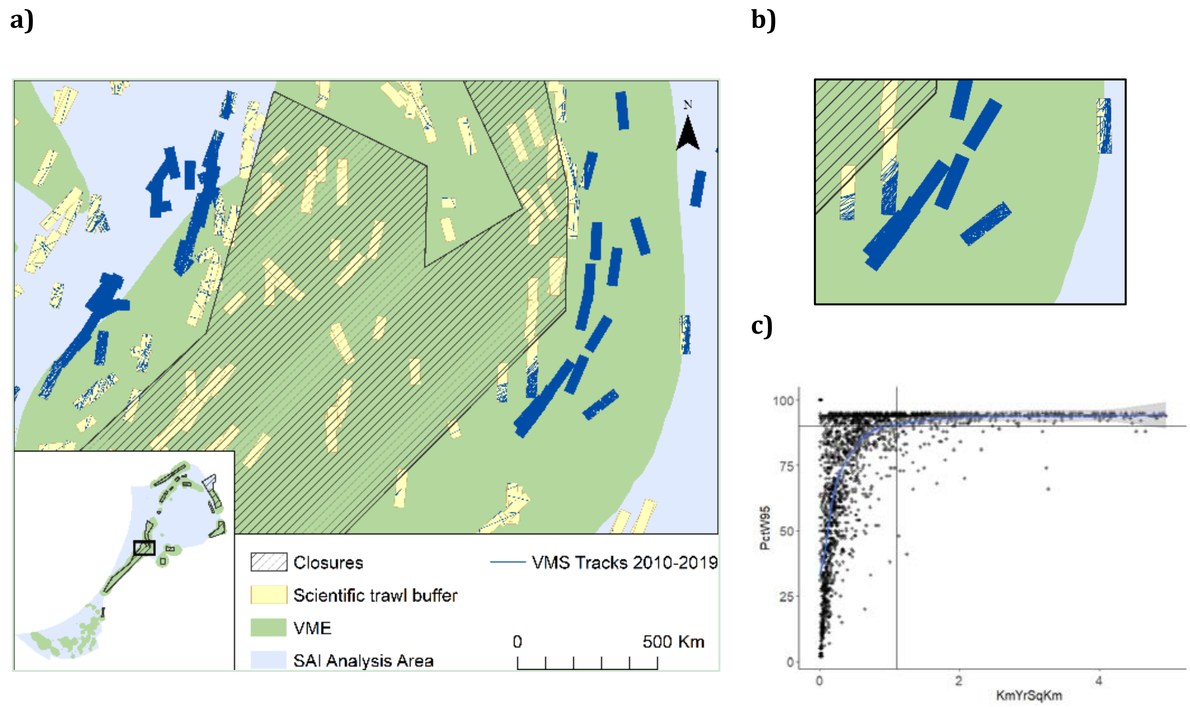

Figure 7.49. VMS track density in sample areas (a), with a close-up (b) and the cut-offs used to remove partially impacted trawls (c). km/km^2/yr = Kilometres per square kilometre per year, PctW95 = Percent of sample area covered by 95% of track lines.

A final data set used for analysis was generated consisting of scientific trawl VME indicator biomass (*kg*) for each VME type with the corresponding mean annual fishing effort (*km/km^2/year*) between 2010 – 2019, including scientific trawls that (1) intersect the VME polygon, but are outside fisheries closures, (2) in which the VME was present, (3) which had associated fishing activity, and (4) have an even effort distribution across the sample area (Table 7.28).

Table 7.28. Numbers of scientific trawls between 2011 - 2019 (inclusive) with observations of each VME type inside the corresponding VME polygon, but excluding fisheries closures (a). The number of trawls with at least one associated VMS track over the ten-year period (2010 - 2019). (b), and the number of trawls remaining when excluding unrepresentative trawls (with uneven distribution of fishing effort)(c).

	Number of Trawls		
	a) All in VME polygon excl. closed areas	**b) With associated Fishing effort**	**c) Included in final data set after filtering for uneven effort distribution**
Black Corals	24	20	20
Boltenia	148	141	137
Bryozoa	60	55	55
Large Gorgonians	20	17	17
Sea Pens	259	234	228
Small Gorgonians	108	99	95
Sponges	288	256	249

4.5.3. Cumulative biomass curves (Step 3)

The level of fishing effort at which high VME biomass no longer occurs in any scientific trawl was considered to indicate a sustained impacted state. The cut-off value for the level of fishing effort corresponding to an 'impacted' *vs* 'at risk' state was determined by plotting cumulative biomass curves, or by using the reciprocal of cumulative biomass to create biomass depletion curves. In both cases the point at which 95% of the biomass is accumulated (or depleted) was taken as the point distinguishing between an 'impacted' *vs* 'at risk' state. A separate analysis was done for each VME type. VME biomass values (*kg*) per scientific trawl were added cumulatively against a gradient of increasing fishing intensity (average $km/km^2/year$ between 2010 - 2019). Plots of cumulative VME indicator species biomass against ranked fishing intensity are shown in Figure 7.50. In all cases there is a clear point where the VME biomass no longer increases at a given level of fishing effort. The fishing effort cut-off value is determined at 95% of the cumulative biomass, which corresponds in most cases to the inflection point in the cumulative biomass response curves (Figure 7.50). The gradient of the response curves is deemed to represent a measure of relative resilience, such that a steep curve is indicative of decreased resilience (or increased sensitivity). In this case, black corals, large and small gorgonians, and sponges are all less resilient (or more sensitive) than *Boltenia* sp., bryozoans and sea pens (Figure 7.50).

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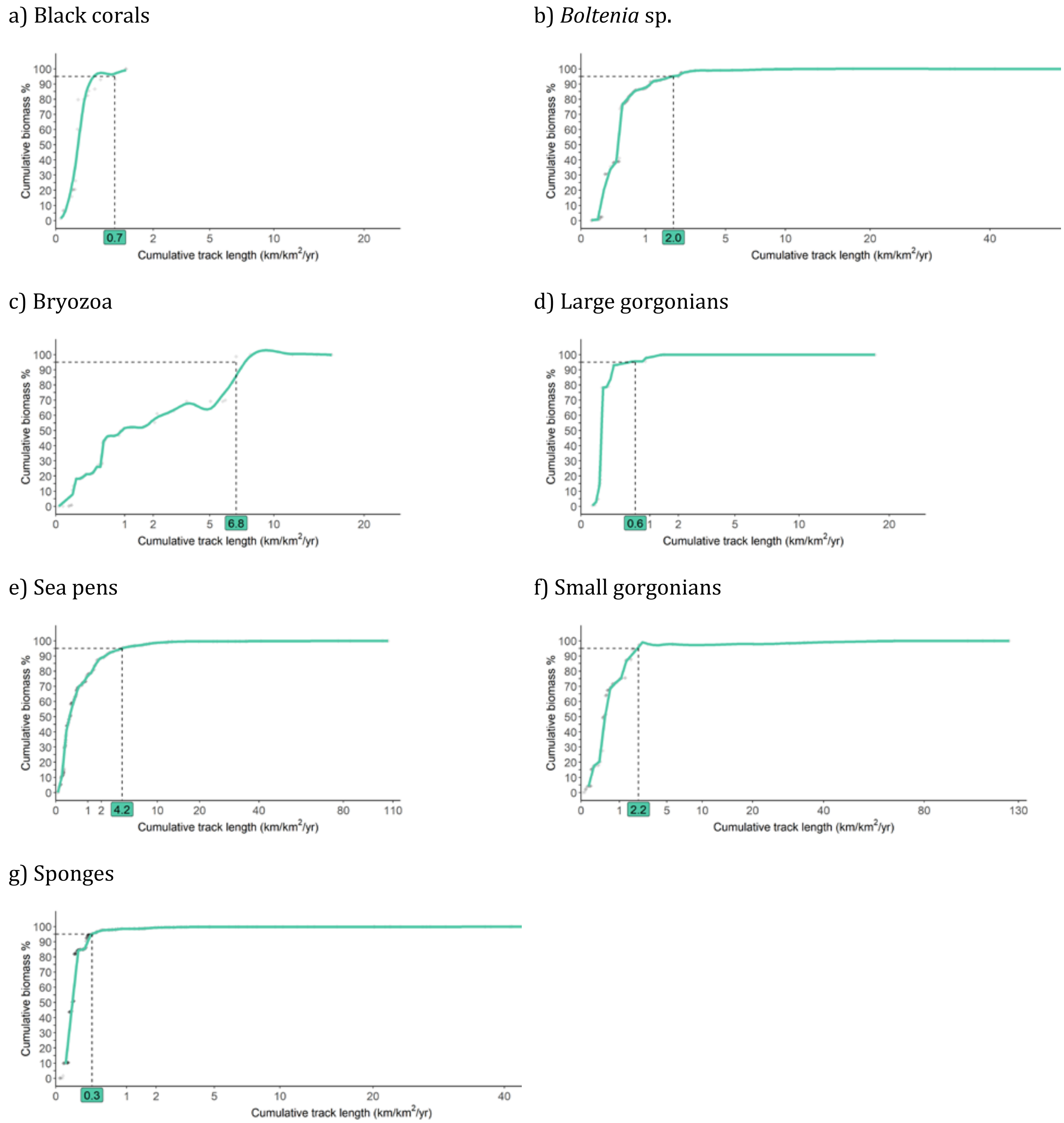


Figure 7.50. Biomass accumulation curves. Dotted lines and highlighted values on the x-axis indicate the fishing effort (in km / km^2 / year) where 95% of total biomass has been accumulated.

To simplify the calculation, the cut-off point taken to represent a limit of fishing effort which separates areas of VME that have been impacted from areas of VME which are at potential risk of impact (unimpacted), was set at the 95% of accumulated biomass. For comparison with the results of the previous analysis undertaken in 2015, the units of fishing effort in the present assessment (*km/km2/yr*) have been converted to their equivalent hrs./km^2/year which were the units used in the previous assessment. The VME-specific cut-off values, the converted effort values, and effort values used in the 2015 assessment are shown for comparative purposes in Table 7.29

Table 7.29. Cut-off values for fishing effort signifying an impacted state based on the VME cumulative biomass curves against ranked fishing effort (km/ km²/year). The cut-off value equals the fishing effort at which 95% of the total biomass has been accumulated. Values are also shown converted into h/km²/year using an estimated average fishing speed of 4 knots for comparison with values resulting from the previous analysis in 2015.

	2020		2015
	km/km²/year	**h/km²/year**	**h/km²/year**
Black Corals	0.7	0.1	
Boltenia	2.0	0.3	-
Bryozoa	6.8	0.9	-
Large Gorgonians	0.6	0.1	0.1
Sea Pens	4.3	0.6	0.5
Small Gorgonians	2.2	0.3	-
Sponges	0.3	0.04	0.3

vi) Assessment of VME biomass/area impacted, at risk of impact and protected (Steps 4 and 5)

For each VME in turn, the corresponding fishing effort cut-off value was applied to the mean fishing effort raster layer to classify cells as either above the cut-off ('impacted') and below the cut-off ('at risk of impact'). All cells with their centre within a fisheries closure were classified as protected by a closure. The same cell centre approach was used to classify cells as inside/outside the NRA fishing footprint and the outer VME polygon boundary. A GIS overlay analysis calculated the total area and biomass of each VME in each impact class. The results are collectively summarised in Table 7.30 (area) Table 7.31 (biomass), and also presented (as maps) separately for each VME type in the following sections.

Table 7.30. Area of VME (as defined by the KDE polygon) that is impacted, at risk and protected. Protected area is further split into CIF =closed area within NAFO footprint, COF=closed area outside NAFO footprint and OFF = outside NAFO footprint.

	Black Coral		***Boltenia***		**Bryozoa**		**Large Gorgonians**		**Sea Pen**		**Small Gorgonians**		**Sponges**	
	Area (km^2)	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**
Impacted	534	19%	817	20%	150	4%	840	16%	810	9%	1,183	25%	4,383	17%
At Risk	1,744	62%	3,247	80%	3,343	96%	1,341	25%	6,815	75%	3,489	73%	5,056	19%
Protected	521	19%	17	0%	5	0%	3,234	60%	1,460	16%	84	2%	16,572	64%
CIF	521	19%	0	0%	5	0%	2072	38%	1,459	16%	75	2%	5,443	21%
COF	0	0%	0	0%	0	0%	846	16%	0	0%	9	0%	4,720	18%
OFF	0	0%	17	0%	0	0%	316	6%	1	0%	0	0%	6,409	25%
Total	2,799	100%	4,081	100%	3,498	100%	5,415	100%	9,085	100%	4,756	100%	26,011	100%

Table 7.31. VME biomass (BM) inside the VME polygon (as defined by the KDE polygon) that is impacted, at risk and protected. Protected area is further split into CIF =closed area within NAFO footprint, COF=closed area outside NAFO footprint and OFF = outside NAFO footprint

	Black Coral		***Boltenia***		**Bryozoa**		**Large Gorgonians**		**Sea Pen**		**Small Gorgonians**		**Sponges**	
	BM (Kg)	**%**	**BM (Kg)**	**%**	**BM (Kg)**	**%**	**BM (Kg)**	**%**	**BM (Kg)**	**%**	**BM (Kg)**	**%**	**BM (Kg)**	**%**
Impacted	922	9%	5,183	12%	353	1%	1,673	1%	1,936	2%	388	12%	1,567,898	1%
At Risk	6,905	66%	36,174	87%	65,210	99%	14,810	11%	62,344	65%	2,902	87%	18,391,708	7%
Protected	2,615	25%	215	1%	4	0%	116,965	88%	32,924	33%	61	2%	257,025,819	93%
CIF	2,615	25%	0	0%	4	0%	77,384	58%	32,900	33%	45	1%	118,784,089	43%
COF	0	0%	0	0%	0	0%	19,773	15%	0	0%	17	1%	94,050,664	34%
OFF	0	0%	215	1%	0	0%	19,808	15%	24	0%	0	0%	44,191,066	16%
Total	10,441	100%	41,572	100%	65,567	100%	133,448	100%	100,244	100%	3,351	100%	276,985,425	100%

Black corals

Figure 7.51 shows the area of black coral VME that is protected, at risk and impacted according to the data presented in Tables 7.30 and 7.31. VME at high risk of impact represents 62% of the black coral VME area and 66% of total black coral VME biomass, whereas 19% of the total black coral VME area and 9% of biomass has been assessed to have been impacted. A total of 19% of the black coral VME area and 25% of biomass falls within the low-risk category, protected by fishery closures inside the fishing footprint.

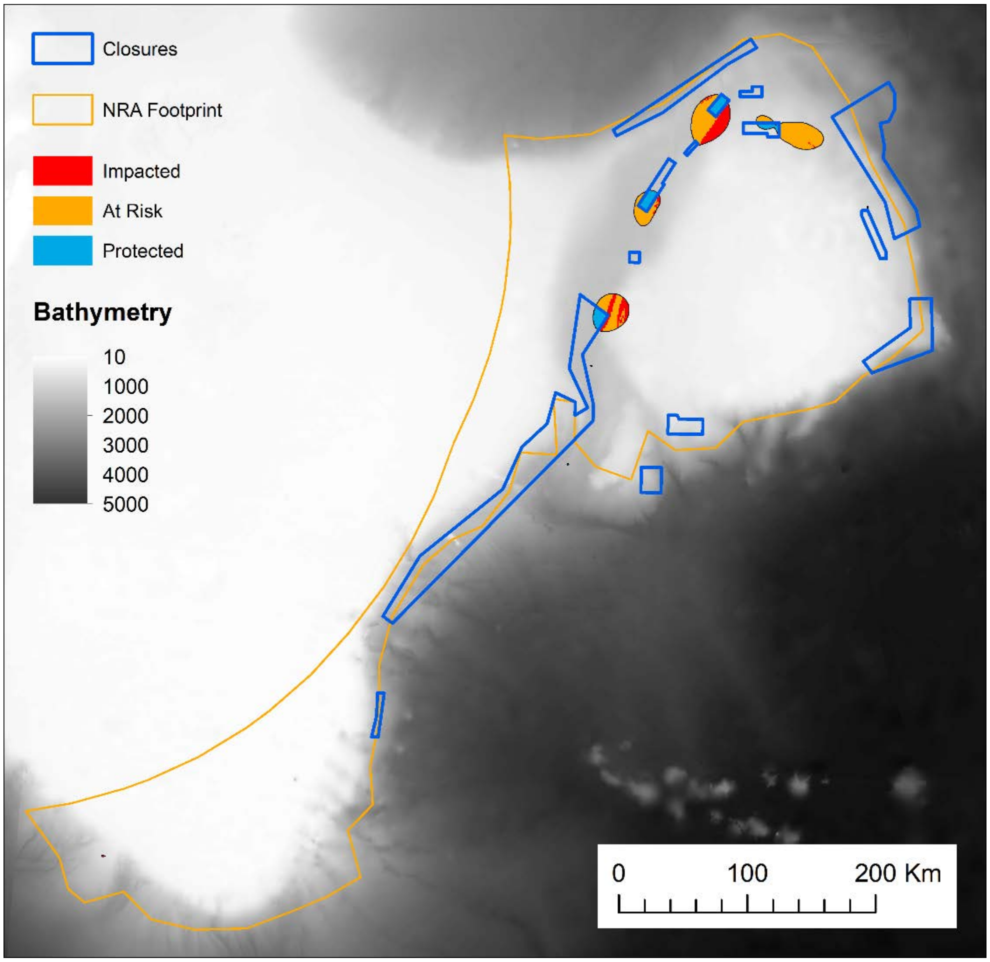


Figure 7.51. Black coral VME classified impacted, at risk and protected, with the boundaries of the NRA fishing footprint and fisheries closures.

Bryozoans

Figure 7.52 shows the area of bryozoan VME that is protected, at risk and impacted according to the data presented in Tables 7.30 and 7.31. VME at high risk of impact represents 96% of the bryozoan VME area and 99% of total bryozoans VME biomass, whereas 4% of the total bryozoan VME area and 1% of biomass has been assessed to have been impacted. A small polygon (<1% of area containing <1% of the biomass) falls inside a fisheries closure within the fishing footprint placing it in the low risk protected category. The area, however, is negligible and the bryozoan VME can be considered fully at risk and with some areas already impacted.

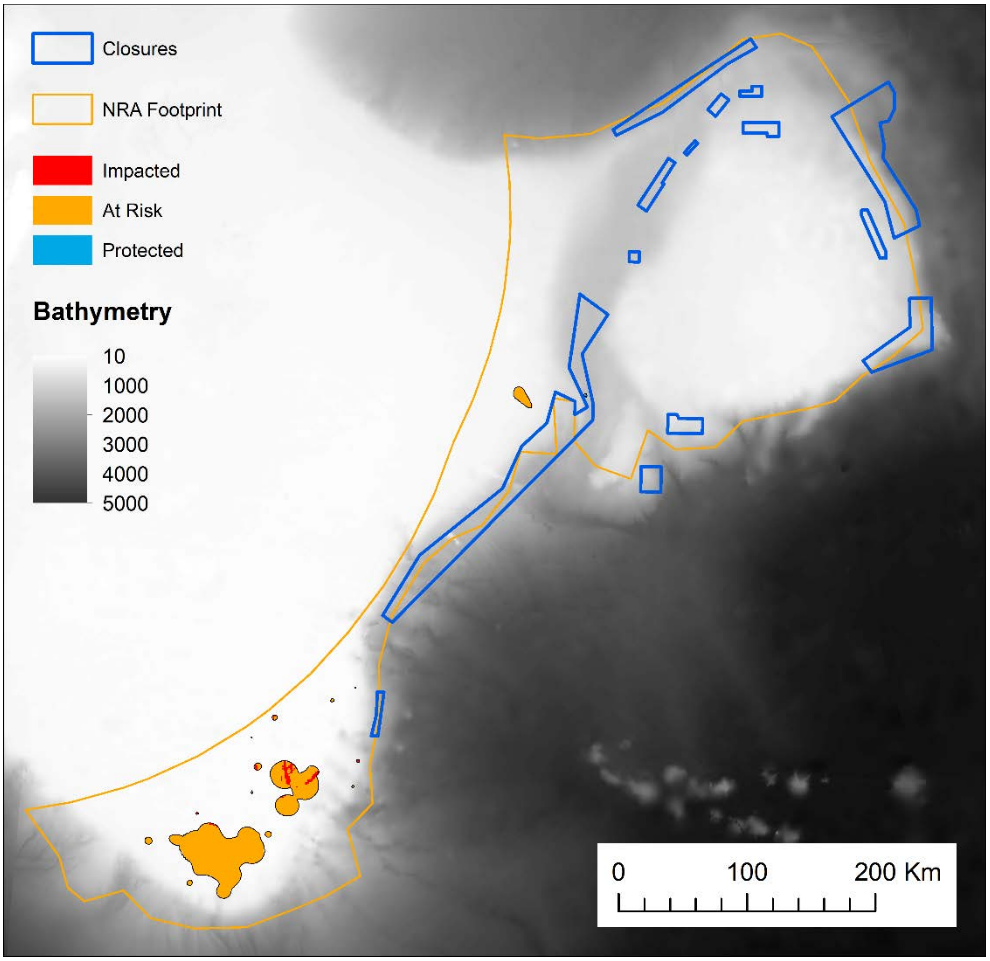


Figure 7.52. Bryozoan VME classified impacted, at risk and protected, with the boundaries of the NRA fishing footprint and fisheries closures.

Large gorgonians

Figure 7.53 shows the area of large gorgonians VME that is protected, at risk and impacted according to the data presented in Tables 7.30 and 7.31. VME at high risk of impact represents 25% of the large gorgonian VME area and 11% of the total large gorgonian VME biomass, whereas 16% of the total large gorgonians VME area and only 1% of biomass has been assessed to have been impacted. A total of 60% of the large gorgonian VME area and 88% of the large gorgonian biomass falls within the protected (low-risk) category, of which 38% of the area and 58% of biomass are protected by fishery closures inside the fishing footprint, 16% of the area and 15% of the biomass are protected by fishery closures outside the fishing footprint, and 6% of area and 15% of biomass fall outside the fishing footprint.

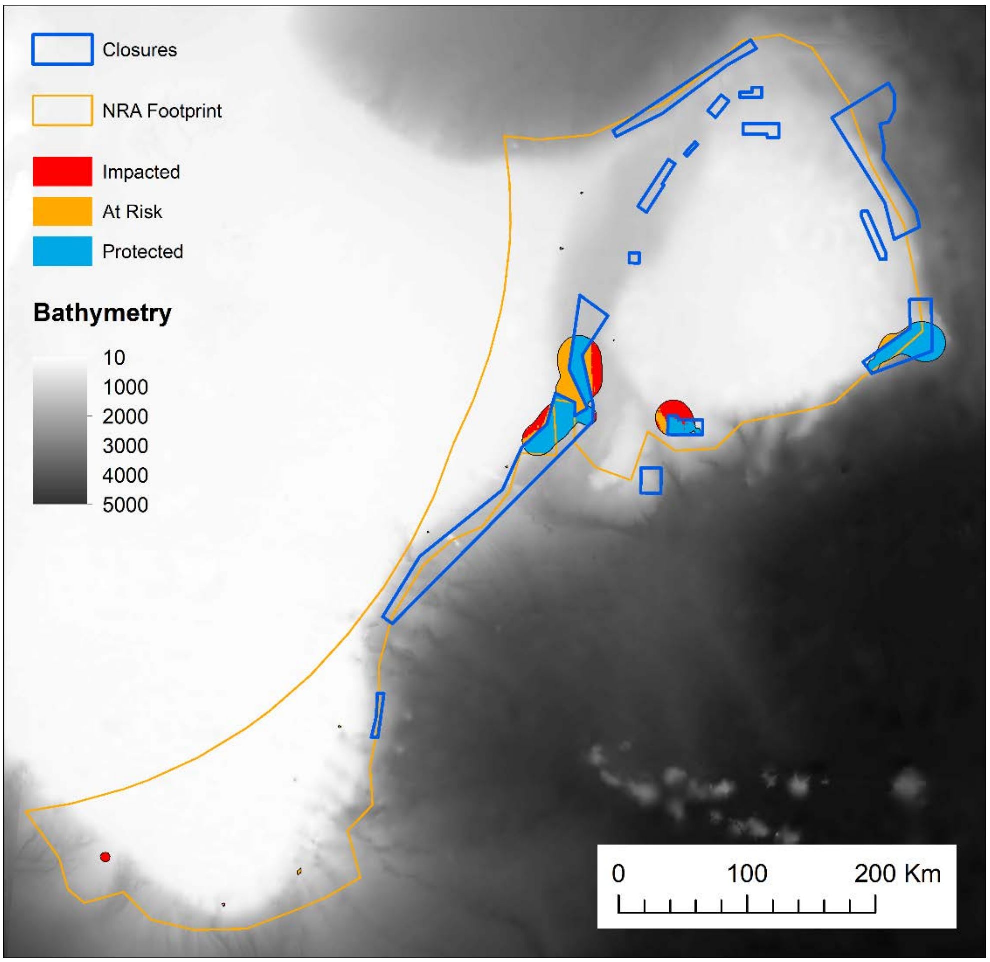


Figure 7.53. Large gorgonian VME classified impacted, at risk and protected, with the boundaries of the NRA fishing footprint and fisheries closures.

Small gorgonians

Figure 7.54 shows the area of small gorgonians VME that is protected, at risk and impacted according to the data presented in Tables 7.30 and 7.31. VME at high risk of impact represents 73% of the total small gorgonian VME area and 87% of total small gorgonian VME biomass, whereas 25% of the small gorgonians VME area and 12% of biomass has been assessed to have been impacted. A total of 2% of the small gorgonians VME area and 2% of biomass falls within the protected (low-risk) category as protected by fishery closures inside and outside the fishing footprint.

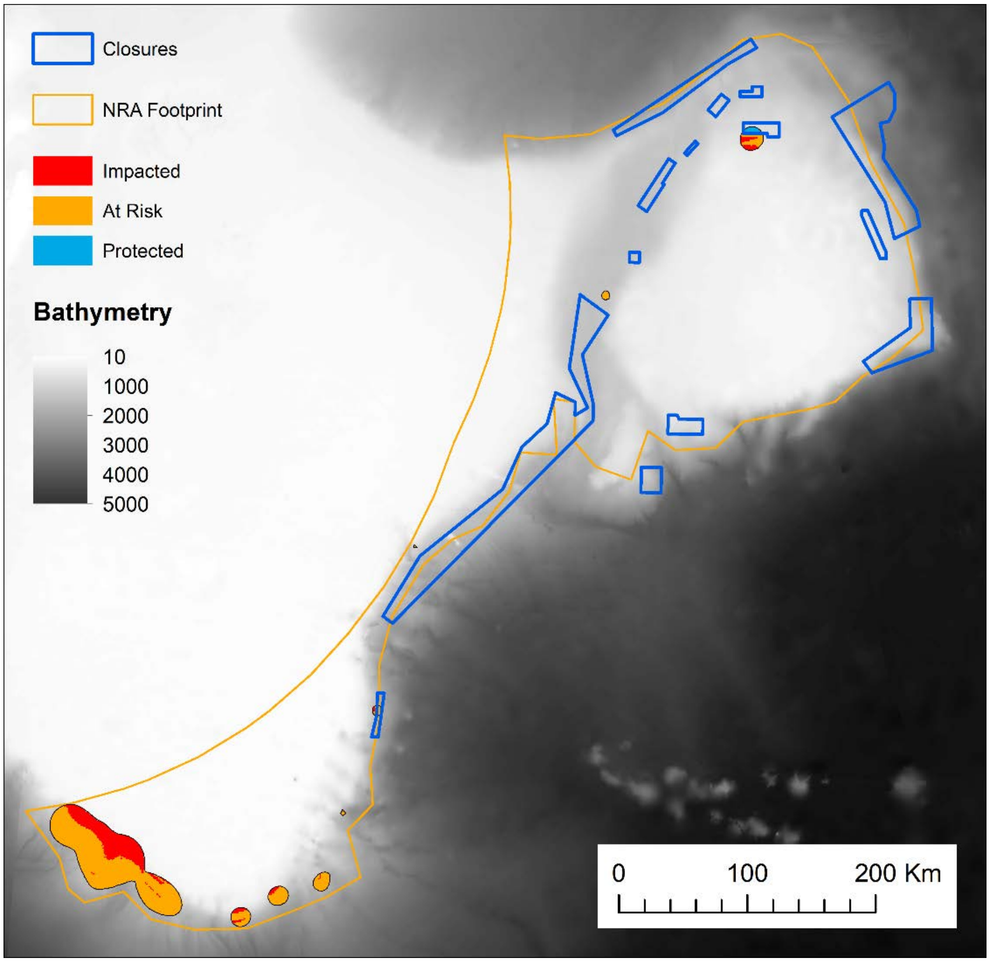


Figure 7.54. Small gorgonian VME classified impacted, at risk and protected, with the boundaries of the NRA fishing footprint and fisheries closures.

Sea squirts

Figure 7.55 shows the area of *Boltenia* VME that is protected, at risk and impacted according to the data presented in Tables 7.30 and 7.31. VME at high risk of impact represents 80% of the total *Boltenia* VME area and 87% of total *Boltenia* VME biomass, whereas 20% of the *Boltenia* VME area and 12% of biomass has been assessed to have been impacted. Only a very small area covering *<1%* of the *Boltenia* VME area and 1% of the biomass falls within the protected (low-risk) as it extends beyond the shallow depth boundary of the fishing footprint on the Grand Banks. While classified as protected in Tables 7.30 and 7.31, aside from its very small size, it occurs on the edge of the fishing footprint bordering the Canadian EEZ of the Grand Banks, and hence cannot truly be regarded as protected or at low risk. Hence the *Boltenia* sp. VME can be considered as a VME fully at risk of impact with parts already impacted.

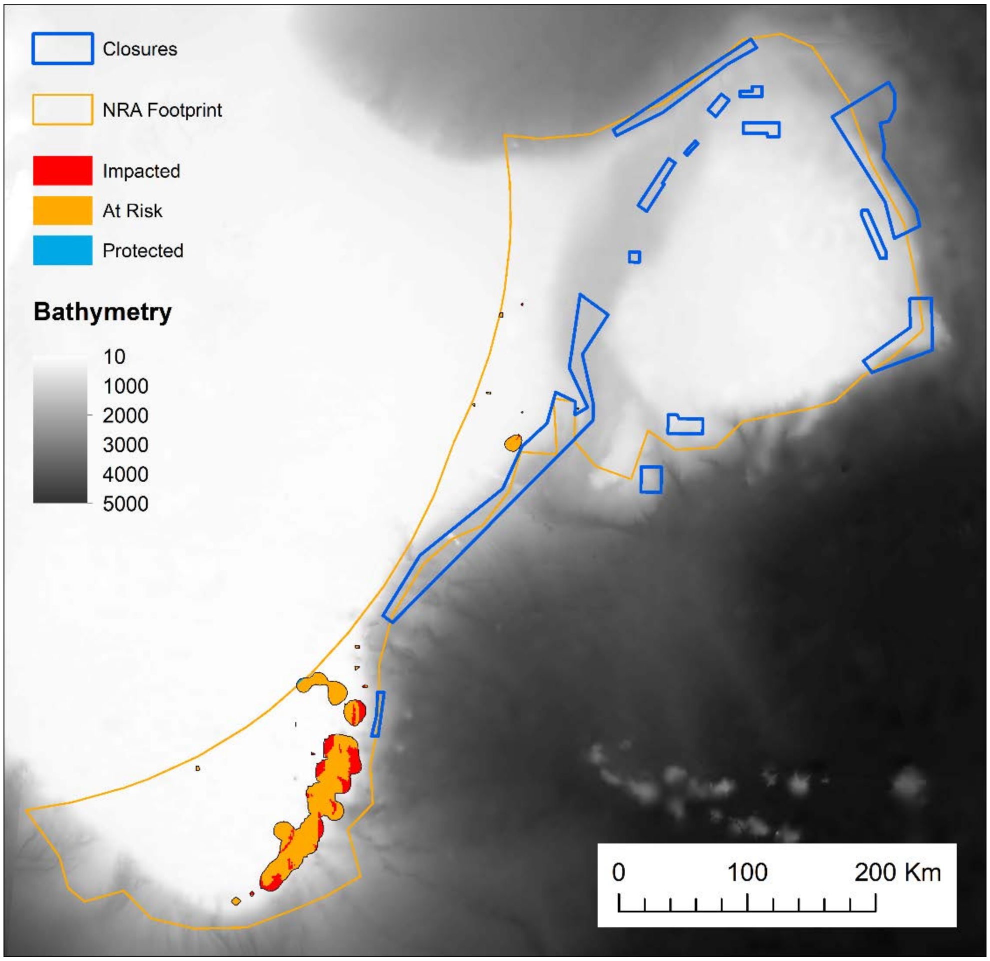


Figure 7.55. Boltenia sp. VME classified impacted, at risk and protected, with the boundaries of the NRA fishing footprint and fisheries closures.

Sea pens

Figure 7.56 shows the area of sea pens VME that is protected, at risk and impacted according to the data presented in Tables 7.30 and 7.31. VME at high risk of impact represents 73% of the total sea pen VME area and 62% of total sea pen VME biomass, whereas 9% of the sea pen VME area and 2% of biomass has been assessed to have been impacted. A total of 18% of the sea pen VME area and 36% of sea pen VME biomass falls within the protected (low-risk) category, protected by fishery closures inside the fishing footprint.

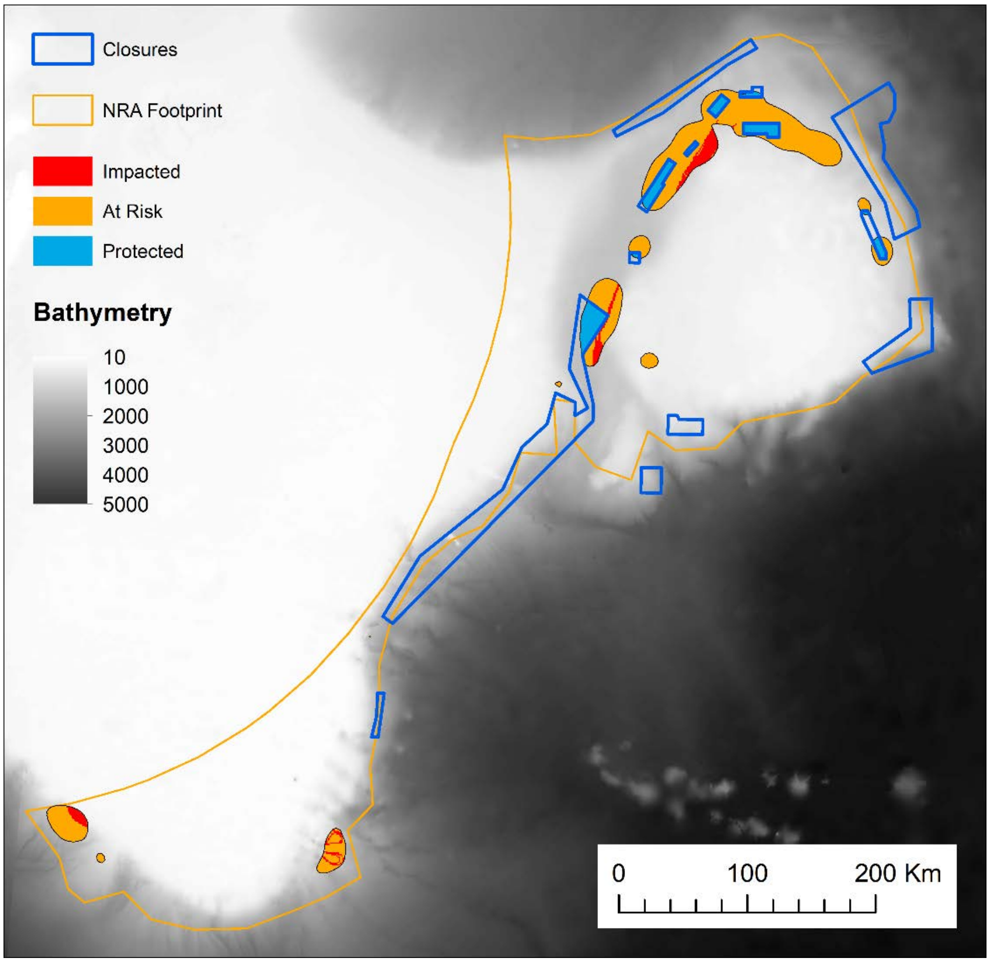


Figure 7.56. Sea pen VME classified impacted, at risk and protected, with the boundaries of the NRA fishing footprint and fisheries closures.

Sponges

Figure 7.57 shows the area of sponges VME that is protected, at risk and impacted according to the data presented in Tables 7.30 and 7.31. VME at high risk of impact represents 19% of the total sponge VME area and 7% of the total sponge VME biomass, whereas 17% of the sponge VME area and 1% of the sponge VME biomass has been assessed to have been impacted. A total of 64% of the sponge VME area and 93% of the sponge VME biomass falls within the protected (low risk) category, of which 21% of the area and 43% of biomass is protected by fishery closures inside the fishing footprint, 18% of the area and 34% of biomass is protected by fishery closures outside the fishing footprint and 25% of area and 16% of the biomass is located outside of the fishing footprint.

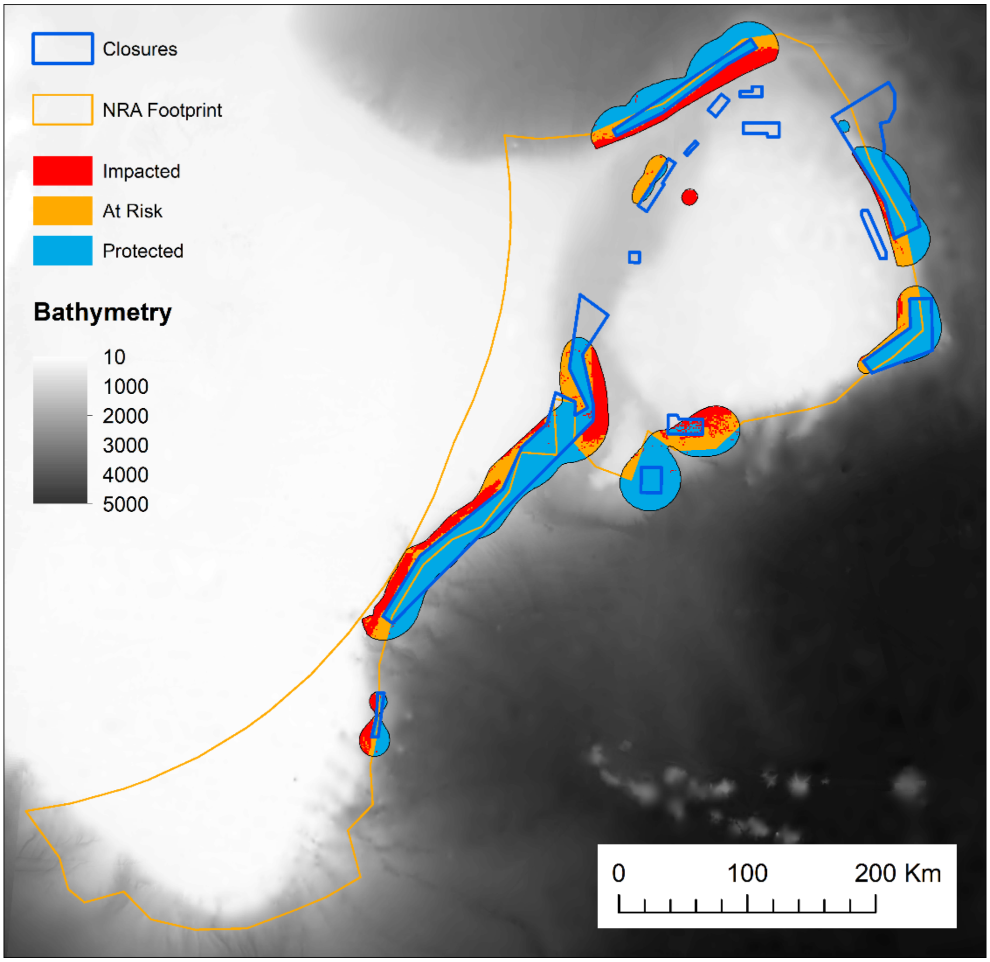


Figure 7.57. Sponge VME classified impacted, at risk and protected, with the boundaries of the NRA fishing footprint and fisheries closures.

vii) Method applied to assess area impacted and at risk of impact of functional groups in VME

The methodology used to assess VME biomass and area impacted and at risk of impact by fisheries was also applied to complete a similar assessment of selected ecosystem functions occurring in the VME. The ecosystem functions included in assessment consist of: (1) Nutrient Cycling, (2) Bioturbation and (3) Habitat Provision. The definition and data used to represent each ecosystem function is described in Section 7.b)iv of this report. The analysis follows the framework, methodology and datasets described in Section 7.d)iii of this report, unless otherwise noted.

The extent of the polygons for the ecosystem functions were determined by applying KDE analysis on scientific trawl biomass data combining groups of taxa by their functional traits (NAFO SCR. 20/071). KDE analysis followed the same approach as used previously to identify the VME polygons and is described in Section 7.b)iv of this report. Full details of each KDE analysis, including figures and tables, are presented in NAFO SCR. 20/071. Comparisons between the biomass datasets sourced from surveys using different gear types and tow lengths led to the KDE analyses being performed separately for the different surveys. The resultant KDE polygons were then combined into a single map to present the full spatial extent of the significant biomass concentrations of each of the ecosystem functions. Bioturbation was divided into bioturbation by fish, and bioturbation by burrowing invertebrate macrofauna. However, due to differences in the types of fishing gears employed by the EU and Canada surveys, combining the biomass data on benthic invertebrates documented from different survey scientific trawls was not possible. Therefore, a single standardised biomass layer could not be generated for this assessment. Furthermore, the spatial extent of the functional polygons did not entirely encompass the full extent of the VME species polygons, which in some cases, *e.g.,* nutrient cycling and habitat provision in the sponge VME, is not realistic. Therefore, the data integration challenges encountered in the present assessment limits the application of the functional analysis in the overall assessment of SAI (*e.g.,* protected, at risk and impacted functional states). Nevertheless, area-based calculations for each functional type and assessment category have been undertaken (see below) and the clear differences observed in the extent and number of functions overlapping with different VME types, can (itself) be used as a potential assessment metric. Nevertheless, options for the creation of a single standardised functional biomass layer and options to address the mismatches in the spatial extent of VME functions and VME species polygons, will be explored ahead of the next (3rd) SAI assessment.

The development of cumulative biomass curves and the determination of fishing impact 'cut-off' values had to be undertaken by individual surveys (for the reasons outlined above), and the separate survey-based results for the impacted and high-risk assessment categories were then combined to create combined polygons for each of the assessment categories. The process of combining the separate results of the functional SAI area-based analysis is shown in Figure 7.58

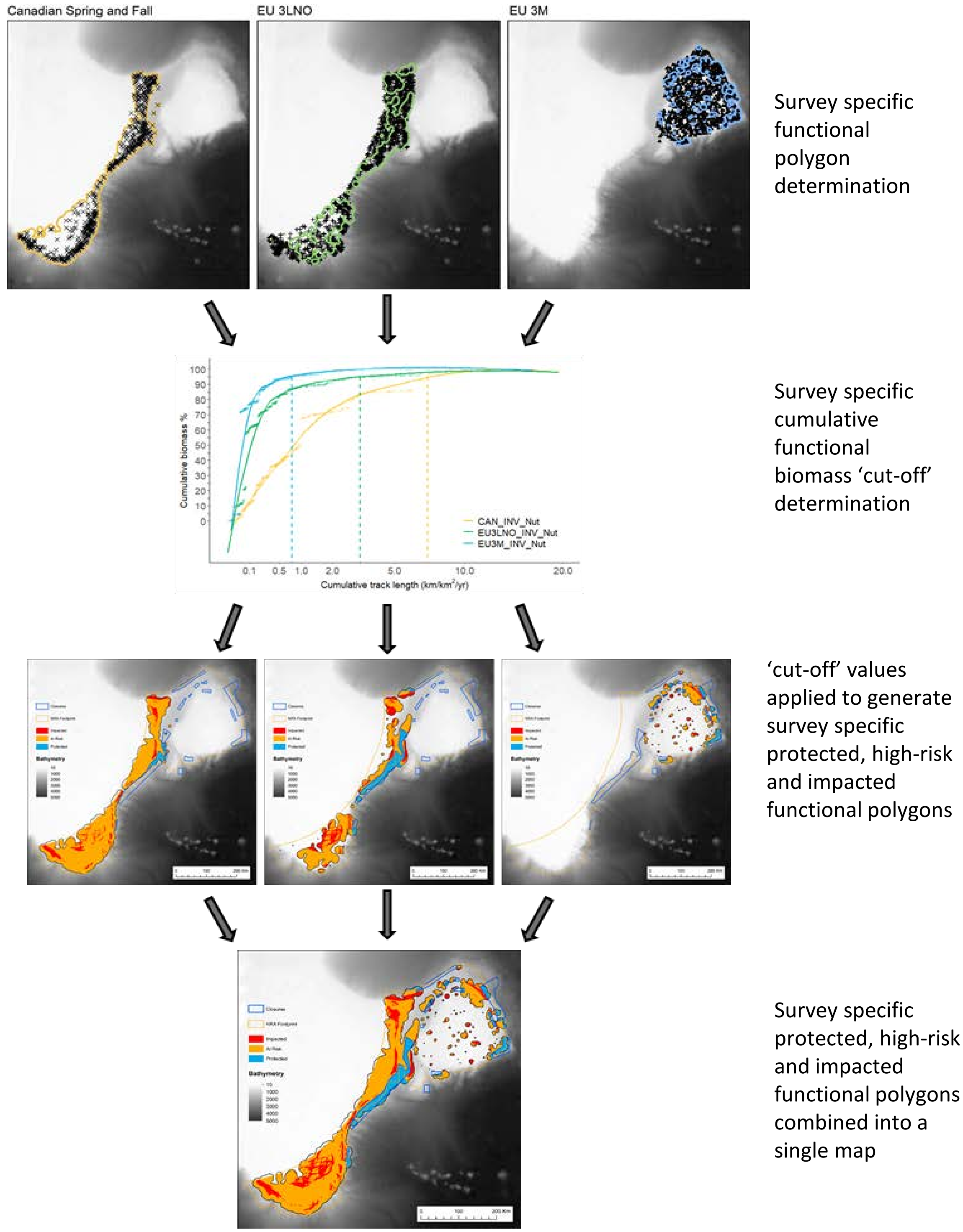


Figure 7.58. Process for classifying the area of each ecological function, based on the individual survey datasets and combining individual outputs into a single polygon for each function representing i. the functional area impacted (red), ii. the functional area protected (blue) and iii. functional area at risk of impact (orange) in the NRA.

viii) Cumulative biomass curves for functions

The threshold value to distinguish between impacted and at risk of impact VME functional states was determined by assessing the accumulation of functional biomass response curves against fishing effort. The analysis utilised the datasets compiled for the KDE analysis, described in detail in Section 7.b)iv. Consequently, separate analyses were carried out for data sourced from Canadian surveys (combined spring and fall), EU division 2LNO surveys and EU division 3M surveys for nutrient cycling, bioturbation by fish and habitat provision. For the invertebrate bioturbation the Canadian fall survey, Canadian spring survey, EU division 2LNO surveys and EU division 3M surveys were all treated separately. The scientific trawls selected for analysis for each function were restricted to those corresponding to the area defined by the corresponding functional KDE polygon. Selected trawls were then further sub-sampled to include only those samples which have associated fishing activity. In addition, and following the procedure outlined in Section 7.d)iii, scientific trawls associated with a mean annual fishing effort > 1.1 km/km^2/year with more than 95% of effort covering less than 90% of the sample area were excluded as unrepresentative (see section 7.d)v).

The functional biomass values (in kg) per scientific trawl were added cumulatively against a gradient of increasing fishing intensity (average km/km^2/year between 2010-2019). Plots of cumulative functional biomass against ranked fishing intensity for each function and survey type are shown in Figure 7.59. Bioturbation appears relatively resilient to increasing fishing effort as illustrated by the gently sloping accumulation curve and the lack of a clearly defined inflection point. This, in part, could be explained by the contribution which motile species such as fish and burrowing species make to this functional type, as these species are potentially less likely to be as sensitive to the effects of bottom contact fishing compared to sessile epibenthic species. By contrast, taxa contributing to the habitat provision and (to some extent) nutrient cycling, are more likely to be sessile epibenthic species which are potentially likely to be more sensitive to the effects of bottom fishing gears. This assertion is supported by the steeper rise in the biomass cumulative curves for these two functions function compared to the other functions (Figure 7.59).

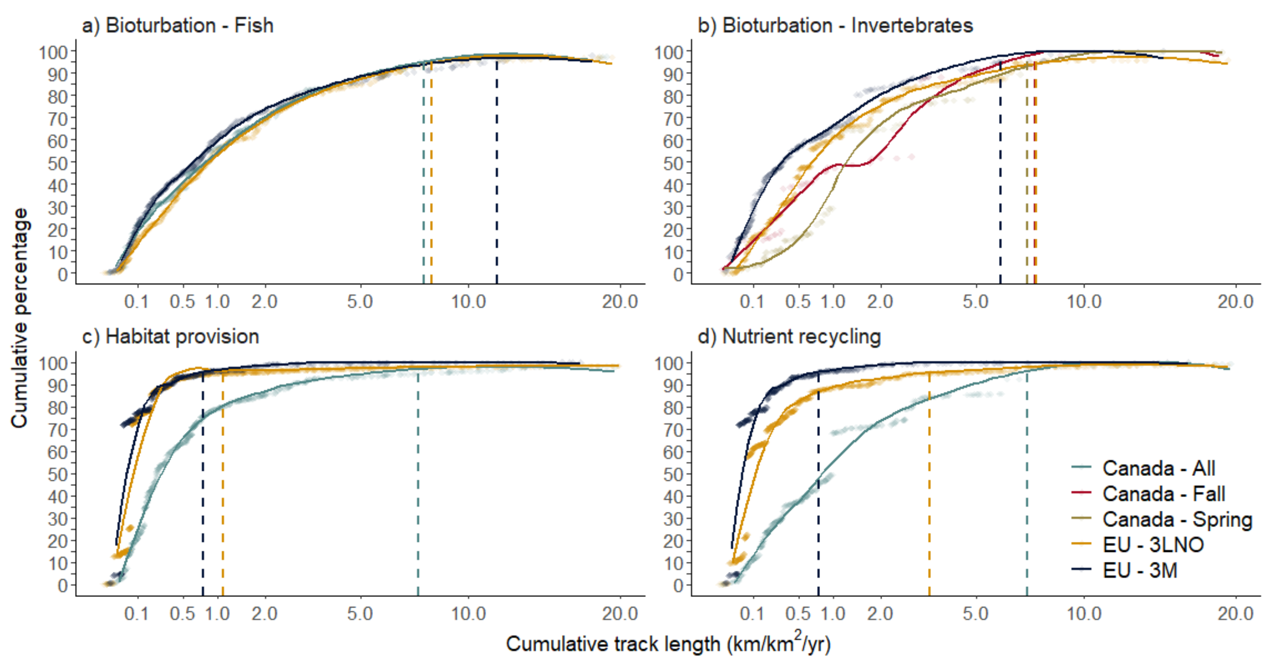


Figure 7.59. Biomass accumulation curves for taxa representing the principal functions assessed for each survey, *e.g.* (a) all fish bioturbators, (b) all invertebrate bioturbators, (c) all invertebrate taxa providing habitat structure and (d) all invertebrate taxa providing a nutrient recycling function. Line colour differentiates data source by the different surveys. Dotted lines indicate the fishing effort (in km/km^2/year) where 95% of total functional biomass has been accumulated.

The determined 'cut-off' points distinguish between those areas of each functional type which have been impacted or at high risk of impact. The specific fishing effort 'cut-off' values as determined by this analysis for each functional type are shown in Table 7.32. Figure 7.60 shows the combined extent of each ecological function type classified into impacted, at risk and protected categories. Where more than one of the individual survey layers overlap, the risk category is set to the highest of the input layers.

Table 7.32. Function and data source specific cut-off values for fishing effort signifying an impacted state based on the accumulation of VME biomass against ranked fishing activity (in km / km2 / year). The threshold value equals the fishing effort at which 95% of the total biomass has been accumulated. Values are also shown converted into h/km2/year using an estimated average fishing speed of 4 knots for comparison with values resulting from the previous analysis in 2015.

Function	Source Survey	N	Sample Weight (Kg)		Threshold	
			Min	Max	km/km^2/year	h/km^2/year
Bioturbation – Fish	Canada - All	373	0.020	2499	7.7	1.0
	EU - 3LNO	442	0.440	2562	8.1	1.1
	EU - 3M	379	0.269	449	11.7	1.6
Bioturbation - Invertebrates	Canada - Fall	49	0.010	71	7.5	1.0
	Canada - Spring	87	0.010	559	7.2	1.0
	EU - 3LNO	446	0.001	233	7.6	1.0
	EU - 3M	238	0.003	7	6.0	0.8
Nutrient Recycling	Canada - All	333	0.010	559	7.2	1.0
	EU - 3LNO	730	0.003	2995	3.4	0.5
	EU - 3M	420	0.002	3226	0.8	0.1
Habitat Provision	Canada - All	533	0.009	89	7.5	1.0
	EU - 3LNO	960	0.001	2995	1.1	0.1
	EU - 3M	541	0.001	3222	0.8	0.1

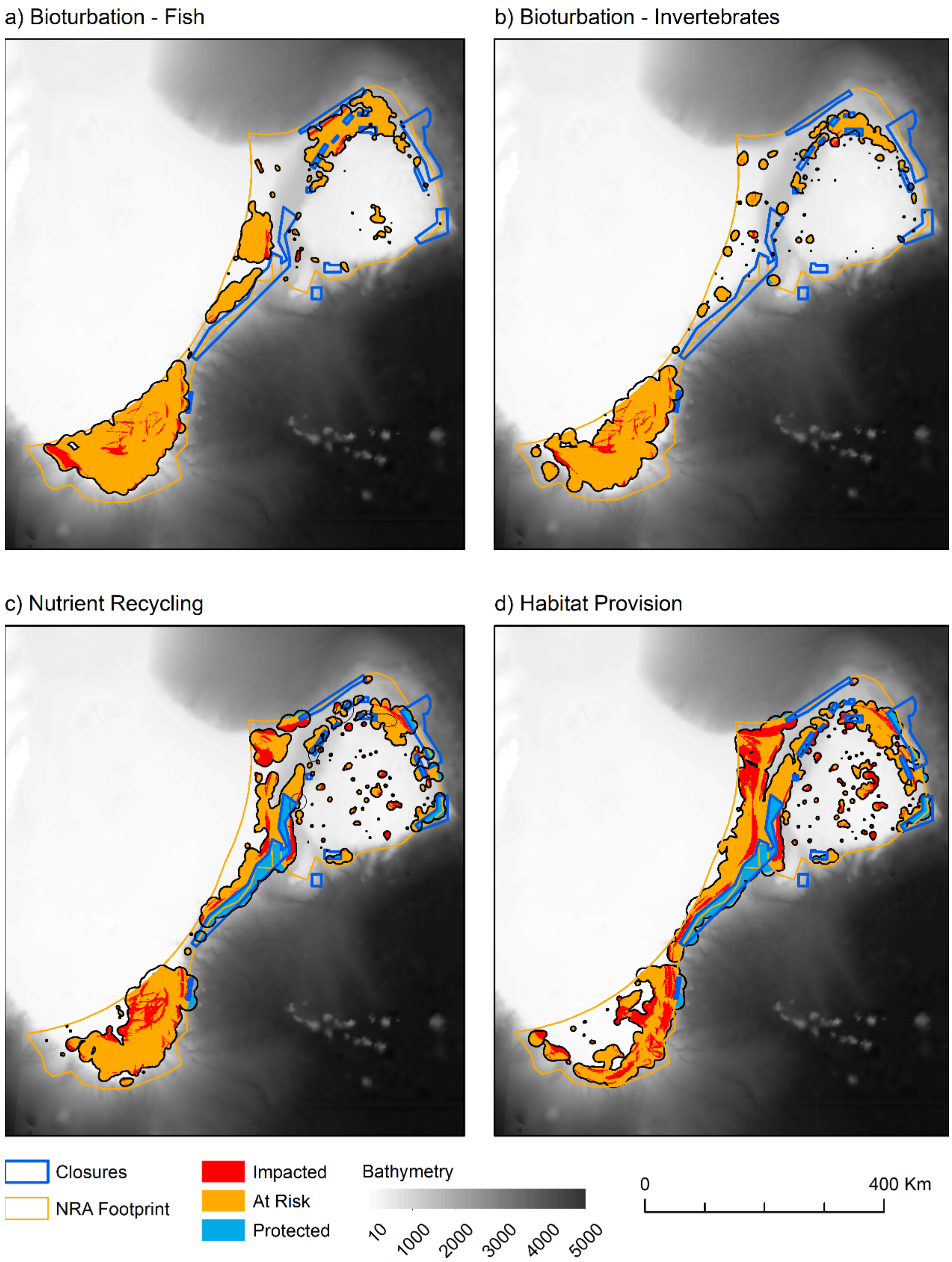


Figure 7.60. Combined extent of impacted, at risk (unimpacted) and protected area for each of the ecological function types.

ix) Assessment of area impacted, at risk of impact and protected for functions by VME type

The following sections quantifies the spatial overlap of the specific VME species polygons with the four functional polygons to assesses what proportion of the functions associated with each VME are impacted, at risk (unimpacted) and protected. However, as noted previously, due to differences in the sample datasets used for the VME species and functional polygon analysis[63], the overlap between specific VME polygons and functional polygons is not 100%, (see Figures 7.61 to 7.67). Nevertheless, the VME functional area-based calculations for each assessment category is provided below:

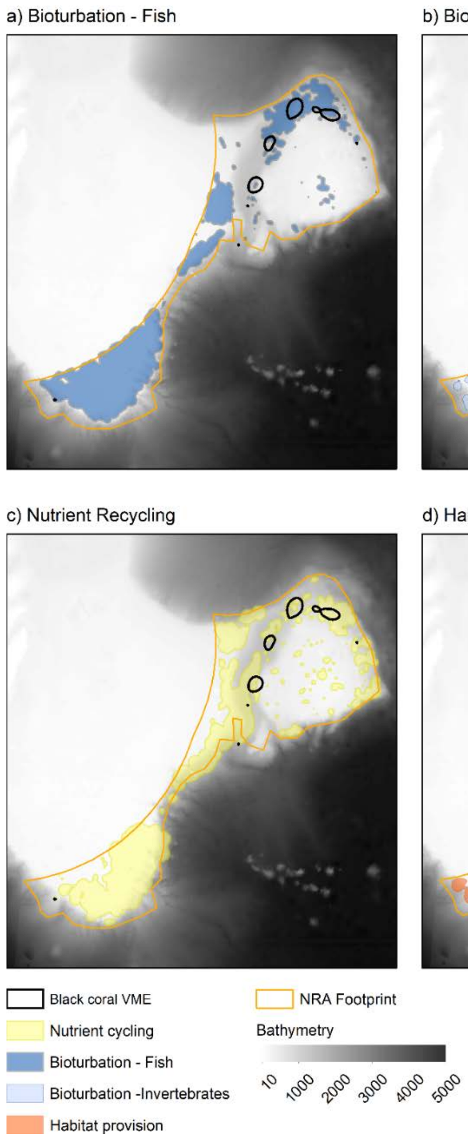


Figure 7.61. The overlap of the four functional types with black coral VME, there is a total of 59%, 45 %, 59%, 68% overlap for bioturbation – fish, bioturbation – invertebrates, nutrient cycling, and habitat provision, respectively.

63 For the functional analysis all invertebrates (not only VME indicator species) were analysed from the scientific survey trawls. As such given the much wider-range in size and structure of the benthic organisms sampled differences in trawl gears is likely to result in large difference in sample species composition, therefore each gear specific survey was treated as a separate data-set.

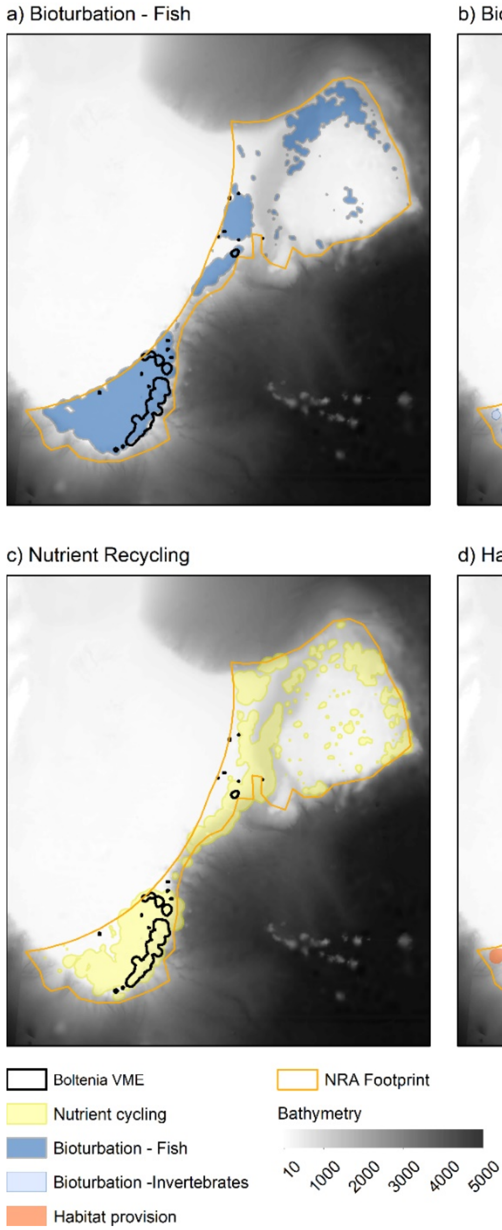


Figure 7.62. The overlap of the four functional types with sea squirt VME, there is a total of 94%, 79%, 97%, 98% overlap for bioturbation – fish, bioturbation – invertebrates, nutrient cycling, and habitat provision, respectively.

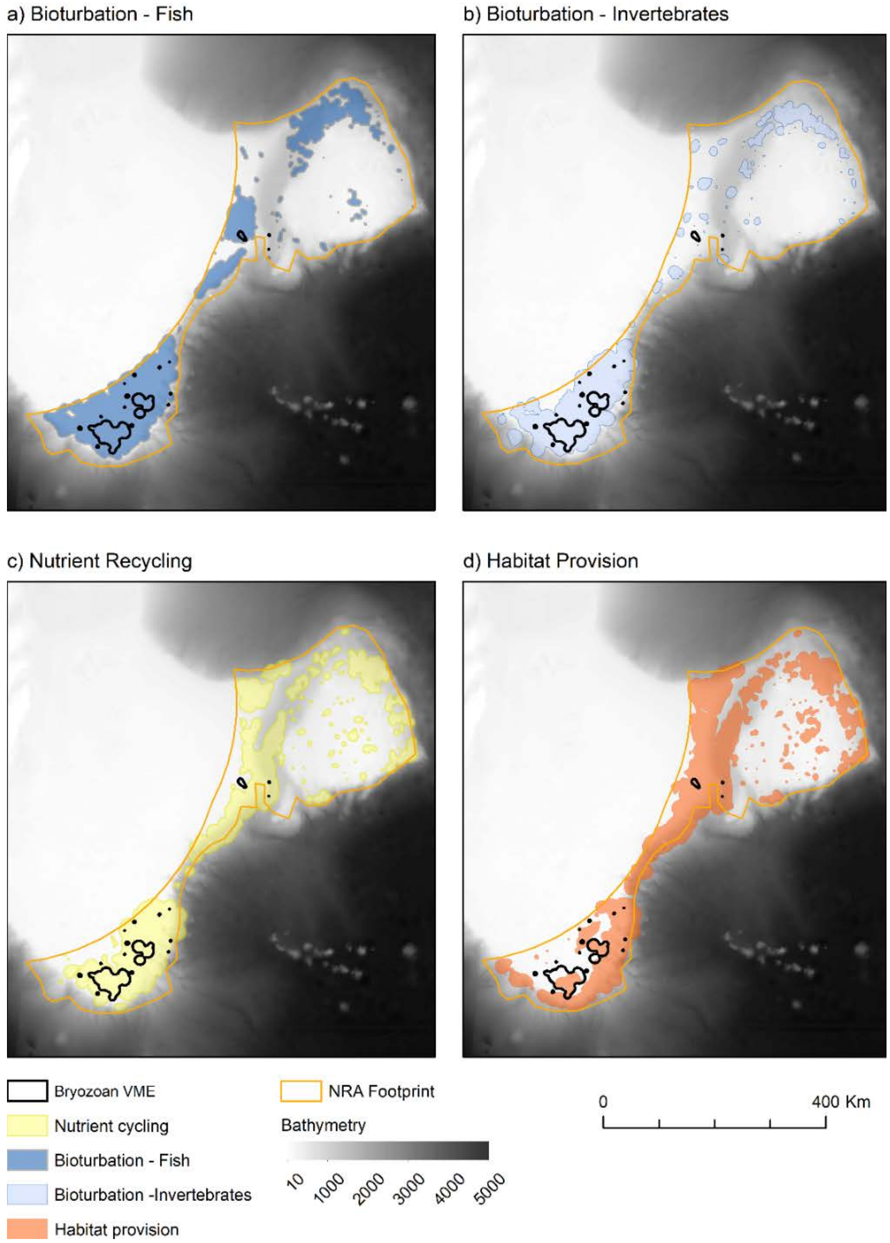


Figure 7.63. The overlap of the four functional types with bryozoan VME, there is a total of 100%, 96%, 96%, 61% overlap for bioturbation – fish, bioturbation – invertebrates, nutrient cycling, and habitat provision, respectively.

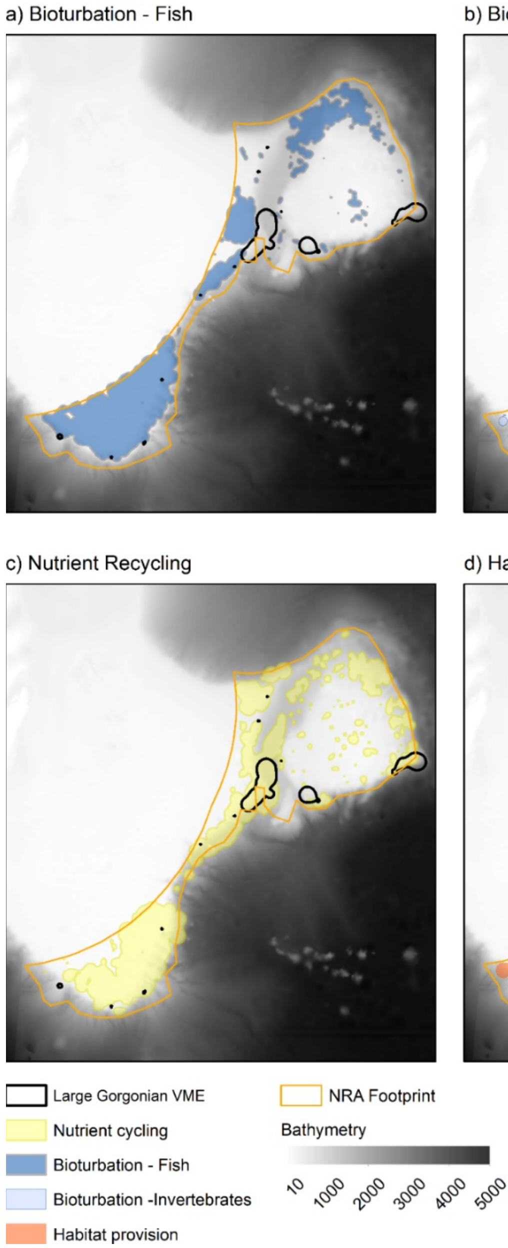


Figure 7.64. The overlap of the four functional types with large gorgonian VME, there is a total of 3%,2%, 75%, 77% overlap for bioturbation – fish, bioturbation – invertebrates, nutrient cycling, and habitat provision, respectively.

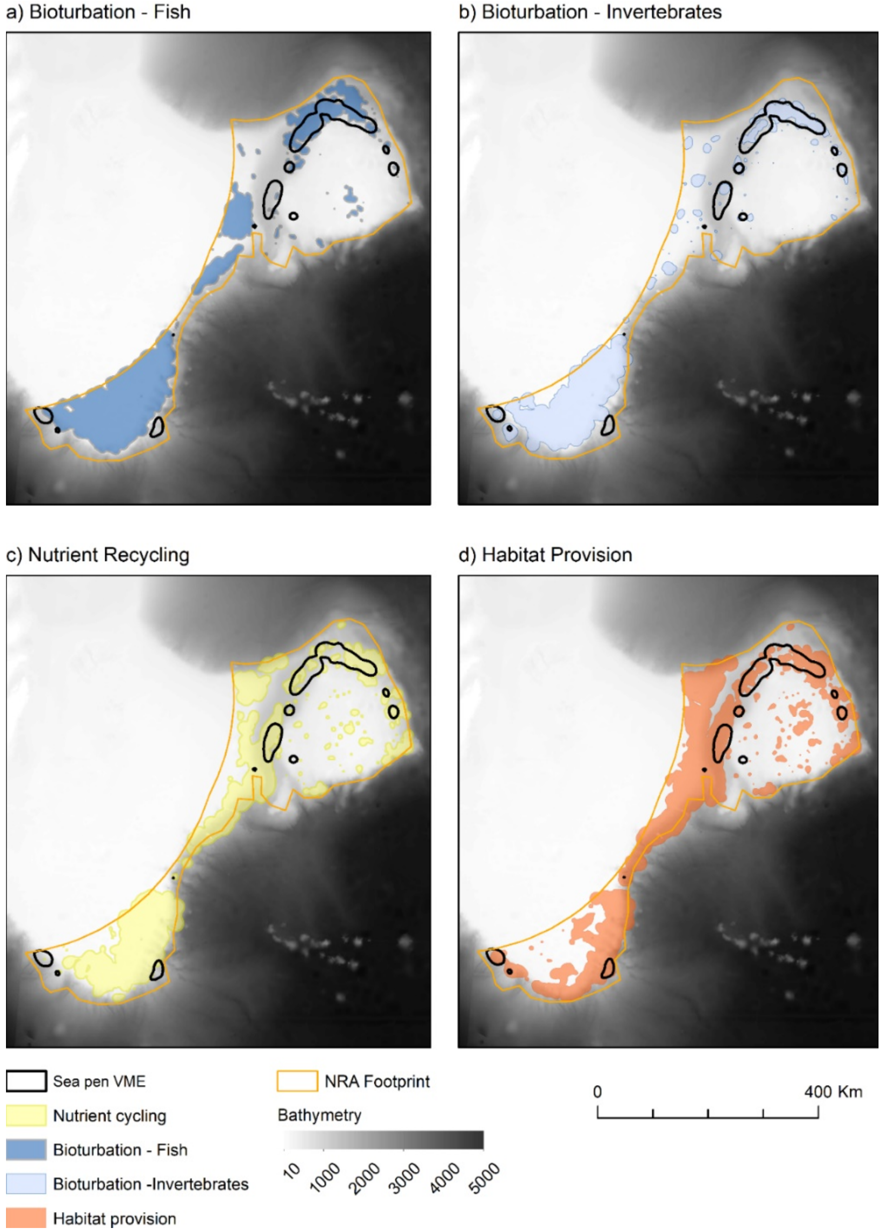


Figure 7.65. The overlap of the four functional types with sea pen VME, there is a total of 54%, 52%, 54%, 76% overlap for bioturbation – fish, bioturbation – invertebrates, nutrient cycling, and habitat provision, respectively.

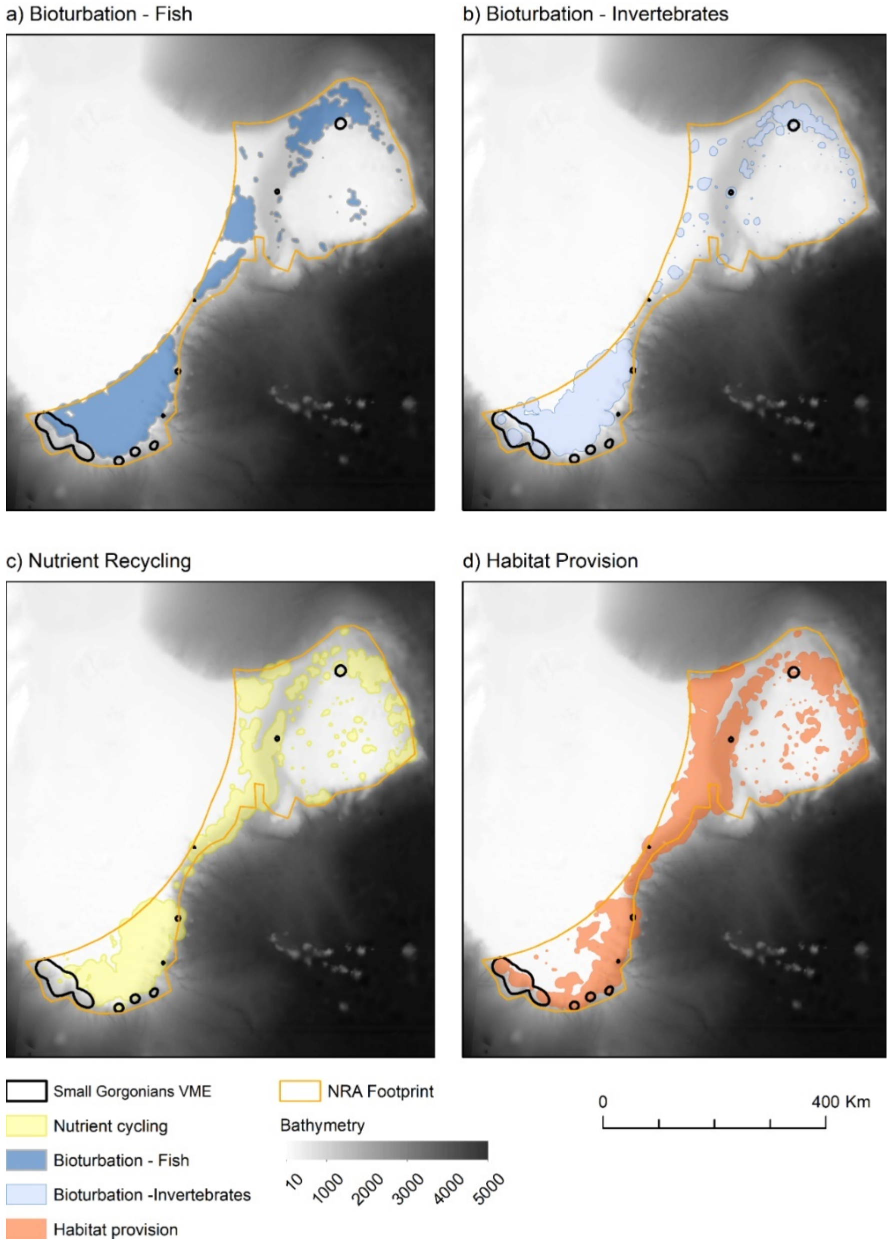


Figure 7.66. The overlap of the four functional types with small gorgonian VME, there is a total of 27%, 41%, 12%, 62% overlap for bioturbation – fish, bioturbation – invertebrates, nutrient cycling, and habitat provision, respectively.

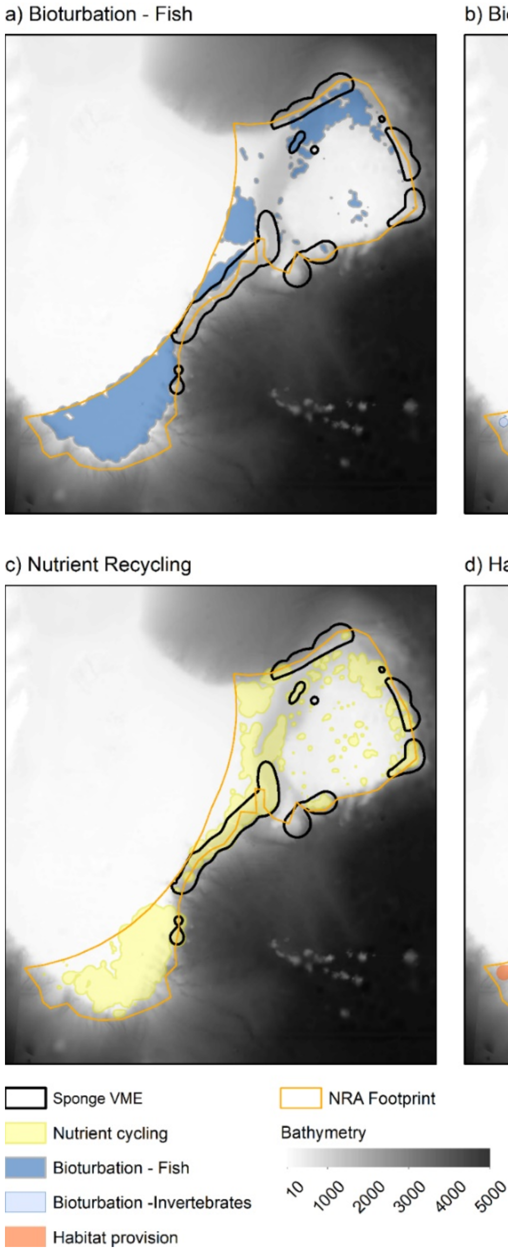


Figure 7.67. The overlap of the four functional types with sponge VME, there is a total of 11%, 4%, 52%, 58% overlap for bioturbation – fish, bioturbation – invertebrates, nutrient cycling, and habitat provision, respectively.

Black corals

Just over half of all the black coral VME overlaps with bioturbation by fish (59%), bioturbation by invertebrates (55%) and nutrient cycling (59%), while over two thirds (68%) overlaps with habitat provision. Table 7.33 and Figure 7.68 show the proportion of the VME functional area impacted, at risk and protected, for each of the four functions inside the black coral VME. Only a small fraction (1-5%) of each function is impacted, whereas most of each function (43-50%) is categorised as being at risk of impact, and between 7-14% of the function is protected.

Table 7.33. Area of Black coral VME (as defined by the KDE polygon) where each of the four functions are impacted, at risk and protected. Protected area is further split into CIF = closed area withing NAFO footprint, COF=closed area outside NAFO footprint and OFF = outside NAFO footprint. VME polygon area with no overlap with the function polygon area is given as not present.

	Bioturbation - Fish		***Bioturbation - Invertebrates***		**Nutrient Recycling**		**Habitat provision**	
Assessment Category	**Area (km²)**	**%**	**Area (km²)**	**%**	**Area (km²)**	**%**	**Area (km²)**	**%**
Not Present	1090	41%	1177	45%	1085	41%	849	32%
Impacted	7	0%	25	1%	122	5%	140	5%
At Risk	1319	50%	1245	47%	1131	43%	1270	48%
Protected	216	8%	185	7%	294	11%	373	14%
CIF	216	8%	185	7%	294	11%	372	14%
COF	0	0%	0	0%	0	0%	0	0%
OFF	0	0%	0	0%	0	0%	1	<1%
Total	2632	100%	2632	100%	2632	100%	2632	100%

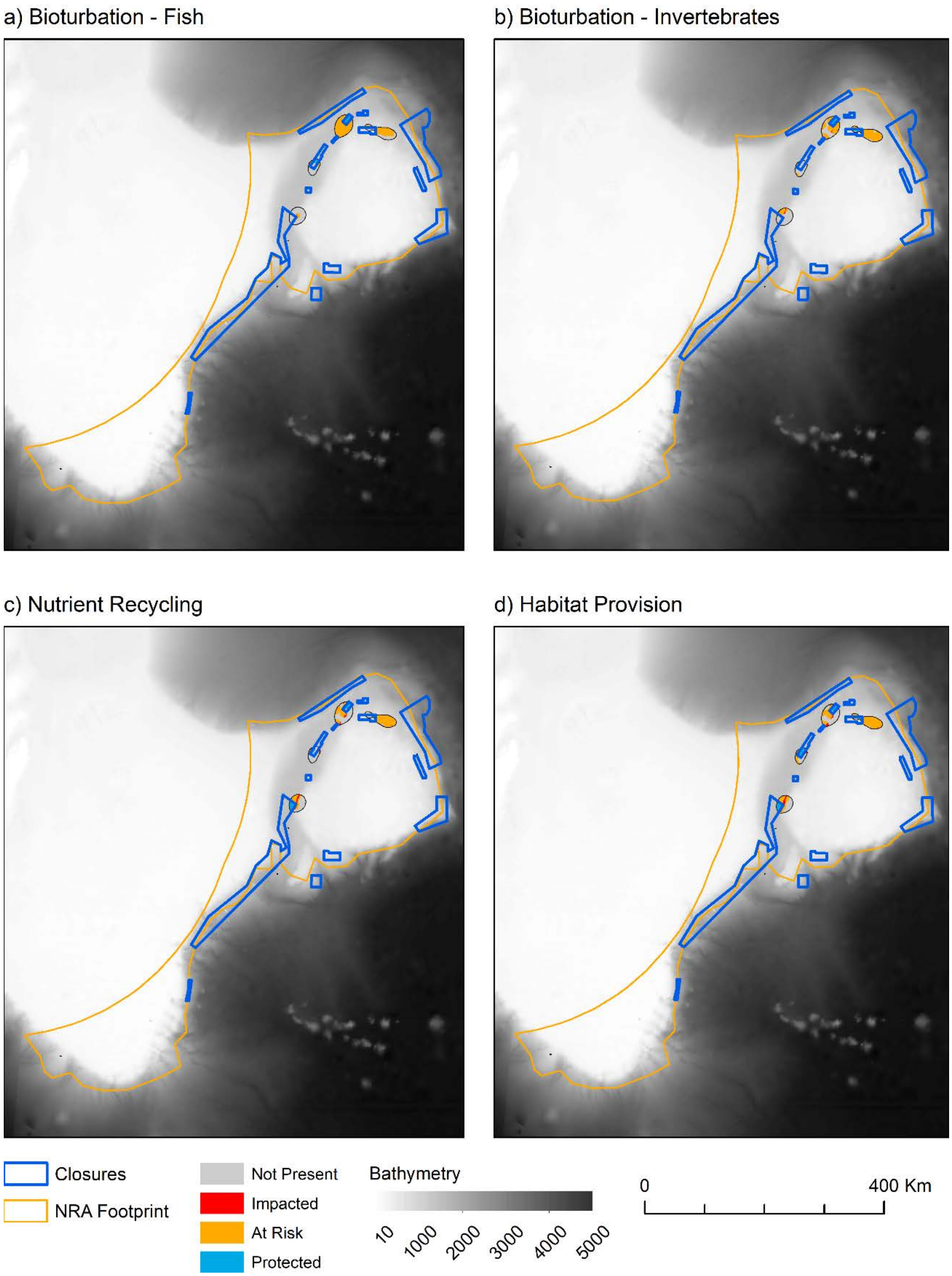


Figure 7.68. Functional groups inside the Black coral VME classified impacted, at risk and protected, with the boundaries of the NRA fishing footprint and fisheries closures.

Bryozoans

The bryozoan VME fully, or almost fully overlaps with bioturbation by fish (100%), bioturbation by invertebrates (96%) and nutrient cycling (96%), while about two thirds (61%) overlaps with habitat provision. Table 7.34 and Figure 6.99 show the proportion of area impacted, at risk of impact and protected, for each of the four functions inside the bryozoan VME. Very little of the VME bioturbation polygon is impacted (3-4%), whereas almost all of it is unimpacted but at high risk (93-97%). Nutrient cycling is similarly largely unimpacted (but at high risk), however the impacted area (13%) is slightly higher than for bioturbation. 41% of the VME overlapping habitat provision function is categorised as being at risk of impact, while 20% of the VME habitat provision function is categorised as impacted. Only negligible areas of the VME functions associated with the bryozoan VME were protected from fishing (<1%).

Table 7.34. Area of Bryozoan VME (as defined by the KDE polygon) where each of the four functions are impacted, at risk and protected. Protected area is further split into CIF =closed area withing NAFO footprint, COF=closed area outside NAFO footprint and OFF = outside NAFO footprint. Area with no overlap with the function is given as not present.

	Bioturbation - Fish		***Bioturbation - Invertebrates***		**Nutrient Recycling**		**Habitat provision**	
	Area (km²)	**%**	**Area (km²)**	**%**	**Area (km²)**	**%**	**Area (km²)**	**%**
Not Present	8	0%	131	4%	139	4%	1360	39%
Impacted	101	3%	126	4%	457	13%	688	20%
At Risk	3389	97%	3236	93%	2897	83%	1445	41%
Protected	0	0%	5	<1%	5	<1%	5	<1%
CIF	0	0%	5	<1%	5	<1%	5	<1%
COF	0	0%	0	0%	0	0%	0	0%
OFF	0	0%	0	0%	0	0%	0	0%
Total	3498	100%	3498	100%	3498	100%	3498	100%

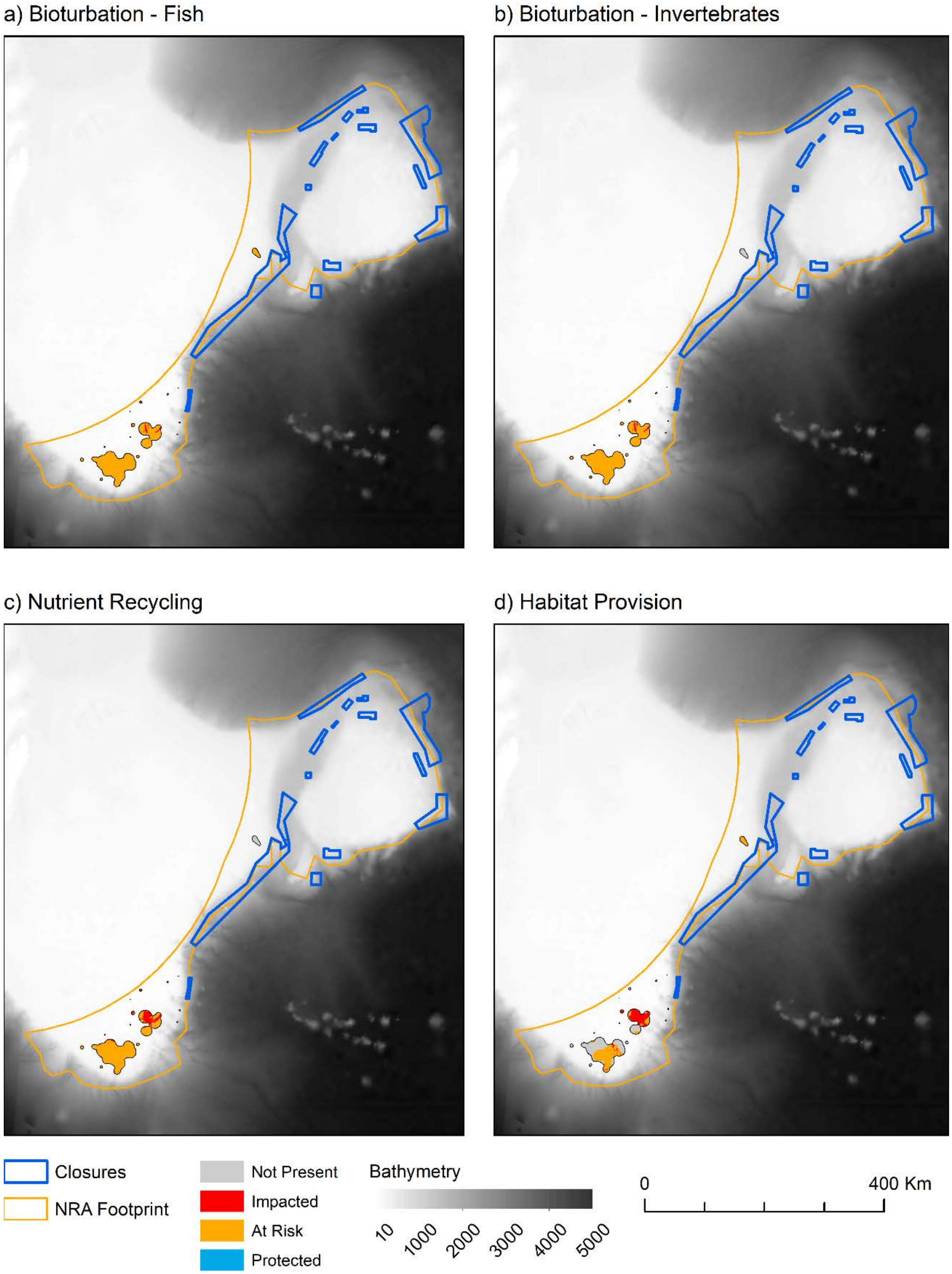


Figure 7.69. Functional groups inside the Bryozoan VME classified impacted, at risk and protected, with the boundaries of the NRA fishing footprint and fisheries closures.

Large gorgonians

The large gorgonian VME shows very little overlap with bioturbation by fish (3%) or invertebrates (2%). Bioturbation is largely limited to soft sediments and large gorgonians are found on hard substrata, either rock or coarse sediments with large cobbles acting as an attachment surface. In contrast, three quarters of the large gorgonian VME overlaps with nutrient cycling (75%) and habitat provision (77%). Gorgonians are both filter feeders and habitat providers growing to a large size and contributing to each of these functional types. Table 7.35 and Figure 7.70 show the proportion of area impacted, at risk and protected for each of the four functions inside the black coral VME. Over half of the area that overlaps with nutrient cycling and habitat provision is protected, in closed area inside and outside of the fishing footprint. Only a small area of each (6-8% of total area) is impacted.

Table 7.35. Area of Large gorgonian VME (as defined by the KDE polygon) where each of the four functions are impacted, at risk and protected. Protected area is further split into CIF =closed area withing NAFO footprint, COF=closed area outside NAFO footprint and OFF = outside NAFO footprint. Area with no overlap with the function is given as not present.

	Bioturbation - Fish		***Bioturbation - Invertebrates***		**Nutrient Recycling**		**Habitat provision**	
	Area (km²)	**%**	**Area (km²)**	**%**	**Area (km²)**	**%**	**Area (km²)**	**%**
Not Present	4858	97%	4925	98%	1243	25%	1178	23%
Impacted	3	0%	2	0%	282	6%	420	8%
At Risk	146	3%	54	1%	1212	24%	1136	23%
Protected	9	<1%	35	1%	2279	45%	2282	45%
CIF	9	<1%	35	1%	1679	33%	1682	34%
COF	0	0%	0	0%	600	12%	600	12%
OFF	0	0%	0	0%	0	0%	0	0%
Total	5016	100%	5016	100%	5016	100%	5016	100%

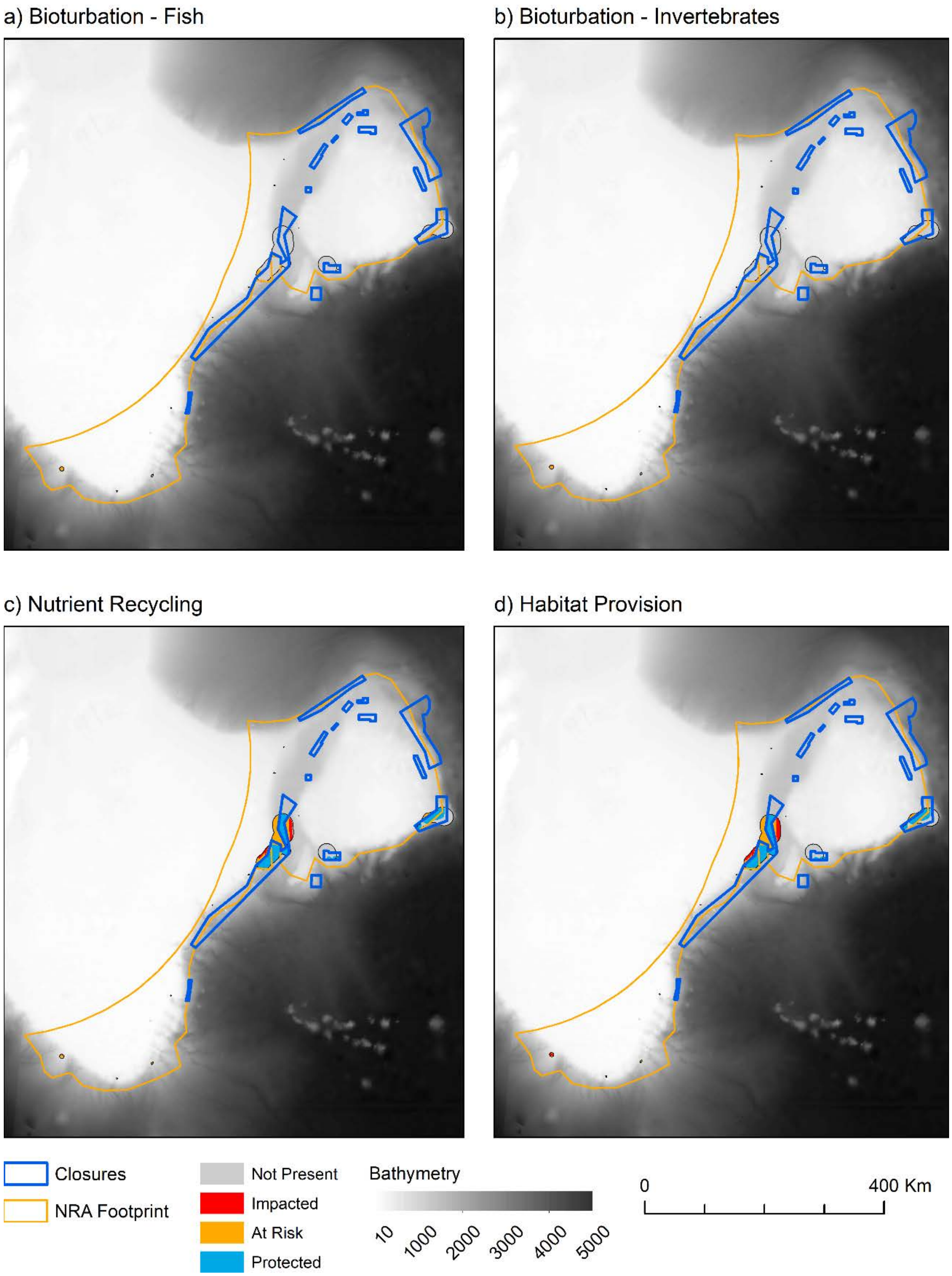


Figure 7.70. Functional groups inside the Large gorgonian VME classified impacted, at risk and protected, with the boundaries of the NRA fishing footprint and fisheries closures.

Small gorgonians

The small gorgonian VME has overlap with bioturbation by fish (27%) and bioturbation by invertebrates (41%). Small gorgonians are found both on bioturbated soft substrata and hard substrata. However, the overlap with nutrient cycling is low (12%), whereas over half (62%) of the small gorgonian VME overlaps with the habitat provision function. Table 7.36 and Figure 7.71 show the proportion of VME functional area; impacted, at risk and protected, for each of the four functional types inside the small gorgonian VME. However, a significant proportion of the small gorgonian VME polygon area (38% - 88%) does not overlap with the defined functional types.

Table 7.36. Area of small gorgonian VME (as defined by the KDE polygon) where each of the four functions are impacted, at risk and protected. Protected area is further split into CIF =closed area withing NAFO footprint, COF=closed area outside NAFO footprint and OFF = outside NAFO footprint. Area with no overlap with the function is given as not present.

	Bioturbation - Fish		***Bioturbation - Invertebrates***		**Nutrient Recycling**		**Habitat provision**	
	Area (km²)	%	Area (km²)	%	Area (km²)	%	Area (km²)	%
Not Present	3295	73%	2687	59%	4017	88%	1740	38%
Impacted	776	17%	286	6%	212	5%	866	19%
At Risk	449	10%	1520	33%	274	6%	1881	41%
Protected	21	<1%	48	1%	38	1%	54	1%
CIF	21	<1%	44	1%	30	1%	46	1%
COF	0	0%	4	<1%	8	<1%	8	<1%
OFF	0	0%	0	0%	0	0%	0	0%
Total	4541	100%	4541	100%	4541	100%	4541	100%

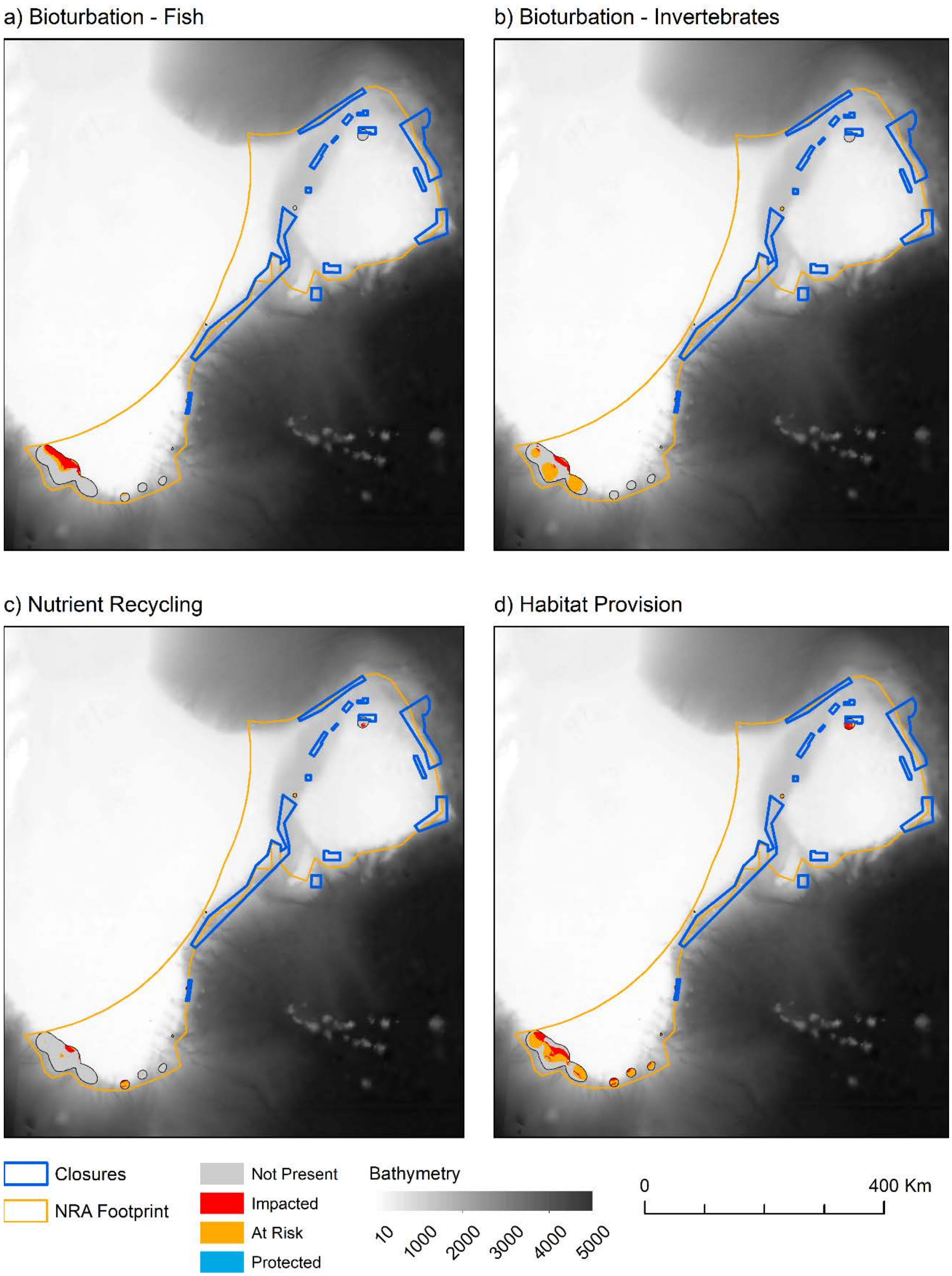


Figure 7.71. Functional groups inside the small gorgonian VME classified impacted, at risk and protected, with the boundaries of the NRA fishing footprint and fisheries closures.

Sea squirts (Ascidians)

The *Boltenia* VME almost fully overlaps with bioturbation by fish (94%), nutrient cycling (97%), and habitat provision (98%), while over three quarters (79%) overlaps with bioturbation by invertebrates. Ascidians are important filter-feeders which contribute to nutrient cycling along with other co-occurring filter-feeding taxa. Table 7.37 and Figure 7.72 show the proportion of area impacted, at risk and protected for each of the four functions inside the sea squirt VME. Most of the area overlapping with the bioturbation functions (fish and invertebrates) as well as nutrient cycling is at risk of impact (86% and 85%, respectively), with only a relatively small area of the VME function being impacted (6 - 12%). However, a third of the habitat provision function (30%) is impacted, with two thirds (67%) being at risk of impact. Very little of the overlapping functions are covered by protected areas (<1%).

Table 7.37. Area of Boltenia spp. VME (as defined by the KDE polygon) where each of the four functions are impacted, at risk and protected. Protected area is further split into CIF=closed area withing NAFO footprint, COF=closed area outside NAFO footprint and OFF=outside NAFO footprint. Area with no overlap with the function is given as not present.

	Bioturbation - Fish		***Bioturbation - Invertebrates***		**Nutrient Recycling**		**Habitat provision**	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Not Present	256	6%	839	21%	112	3%	100	2%
Impacted	285	7%	227	6%	486	12%	1212	30%
At Risk	3523	86%	2998	73%	3466	85%	2752	67%
Protected	16	<1%	16	<1%	16	<1%	16	<1%
CIF	0	0%	0	0%	0	0%	0	0%
COF	0	0%	0	0%	0	0%	0	0%
OFF	16	<1%	16	<1%	16	<1%	16	<1%
Total	4081	100%	4081	100%	4081	100%	4081	100%

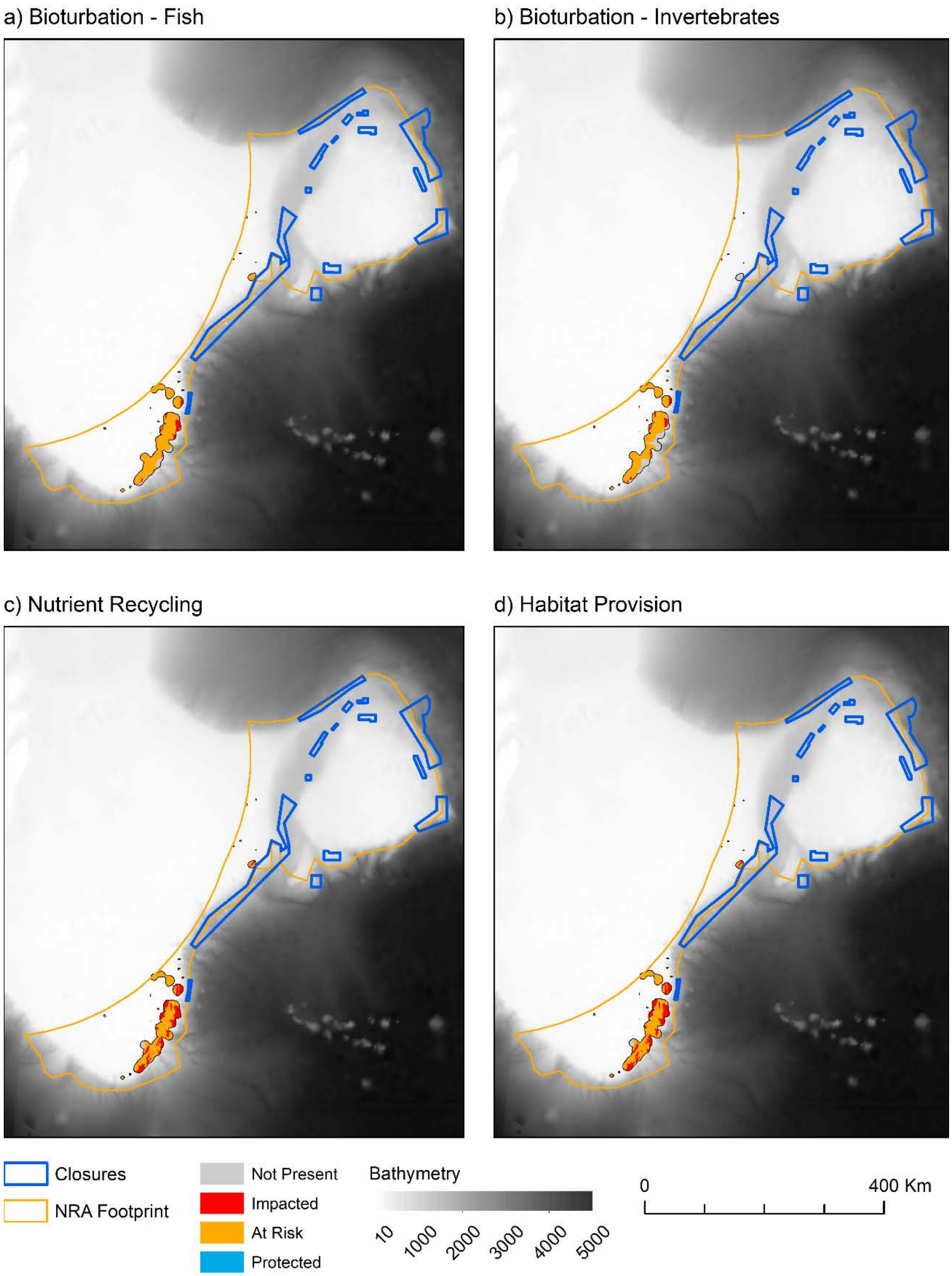


Figure 7.72. Functional groups inside the Boltenia VME classified impacted, at risk and protected, with the boundaries of the NRA fishing footprint and fisheries closures.

Sea pens

Just over half of the sea pen VME overlaps with the bioturbation functions (by fish and invertebrates, 54% and 52%, respectively) and nutrient cycling (54%), while over three quarters of the sea pen VME (76%) overlaps with the habitat provision function. Sea pens occur on soft sediments and are predominantly suspension feeding animals which contribute to the nutrient cycling function. Table 7.38 and Figure 7.73 show the proportion of the area impacted, at risk of impact and protected for each of the four functions inside the sea pen VME. Most of the bioturbation functions (by fish and invertebrates) are at risk of impact (44% and 45%, respectively), whereas only 1% - 3% of the functional area is impacted with 6% - 7% of the function protected. The nutrient cycling function within the sea pen VME is mostly at risk of impact (35% of total area), it also has a higher proportion of both impacted (6% of total area) and protected (12% of total area) categories. About half of the overlapping habitat provision function is at risk of impact (48%) while 14% is protected and 15% is impacted.

Table 7.38. Area of sea pen VME (as defined by the KDE polygon) where each of the four functions are impacted, at risk and protected. Protected area is further split into CIF =closed area withing NAFO footprint, COF=closed area outside NAFO footprint and OFF = outside NAFO footprint. Area with no overlap with the function is given as not present.

	Bioturbation - Fish		***Bioturbation - Invertebrates***		**Nutrient Recycling**		**Habitat provision**	
	Area (km²)	**%**	**Area (km²)**	**%**	**Area (km²)**	**%**	**Area (km²)**	**%**
Not Present	3938	46%	4058	48%	3936	46%	2008	24%
Impacted	229	3%	87	1%	540	6%	1251	15%
At Risk	3809	45%	3768	44%	2983	35%	4071	48%
Protected	519	6%	582	7%	1036	12%	1165	14%
CIF	519	6%	582	7%	1036	12%	1165	14%
COF	0	0%	0	0%	0	0%	0	0%
OFF	0	0%	0	0%	0	0%	0	0%
Total	8495	100%	8495	100%	8495	100%	8495	100%

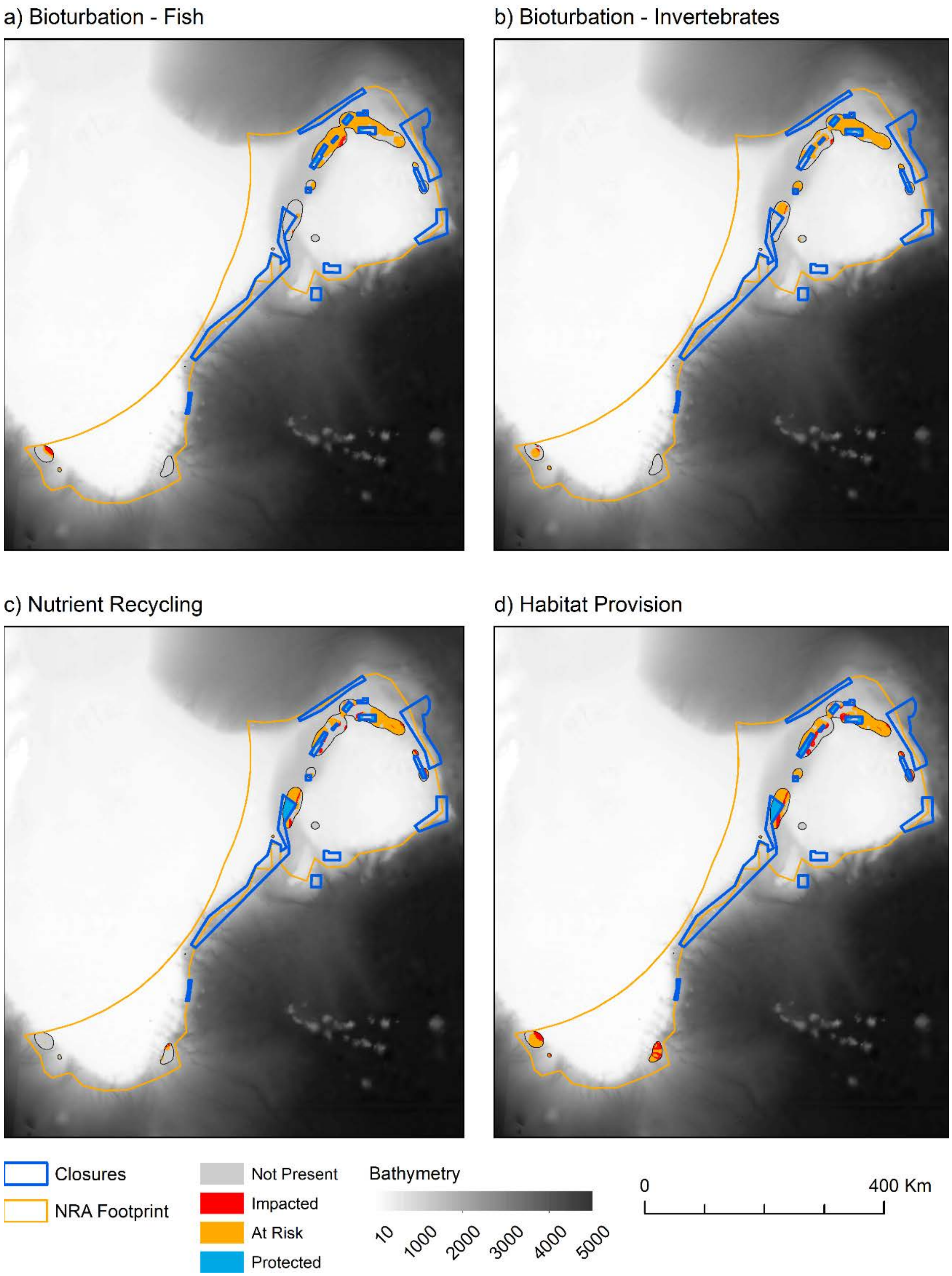


Figure 7.73. Functional groups inside the sea pen VME classified impacted, at risk and protected, with the boundaries of the NRA fishing footprint and fisheries closures.

Sponges

Only a small area of the sponge VME overlaps with the bioturbation functional polygons (by fish and invertebrates; 11% and 4%, respectively). The sponge aggregations mainly occur on coarse sediment, which have little bioturbation. Around half of the VME overlaps with nutrient cycling (52%) and habitat provision (58%). Sponges are both nutrient recyclers and habitat providers. Table 7.39 and Figure 7.74 show the proportion of the area impacted, at risk and protected for each of the four functions inside the black coral VME. Approximately half (29-31% of total area) of both nutrient cycling and habitat provision overlapping with the sponge VME is protected, while just under half (20% of total area) is at risk of impact, with a further 4 - 7% of the function polygon area within the VME impacted.

Table 7.39. Area of sponge VME (as defined by the KDE polygon) where each of the four functions are impacted, at risk and protected. Protected area is further split into CIF=closed area withing NAFO footprint, COF=closed area outside NAFO footprint and OFF=outside NAFO footprint. Area with no overlap with the function is given as not present.

	Bioturbation - Fish		***Bioturbation - Invertebrates***		**Nutrient Recycling**		**Habitat provision**	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Not Present	21679	89%	23362	96%	11590	48%	10192	42%
Impacted	188	1%	36	<1%	919	4%	1678	7%
At Risk	2164	9%	546	2%	4740	20%	4739	20%
Protected	200	1%	287	1%	6981	29%	7622	31%
CIF	197	1%	142	1%	3562	15%	3732	15%
COF	0	0%	34	<1%	2402	10%	2586	11%
OFF	3	<1%	111	<1%	1018	4%	1304	5%
Total	24231	100%	24231	100%	24231	100%	24231	100%

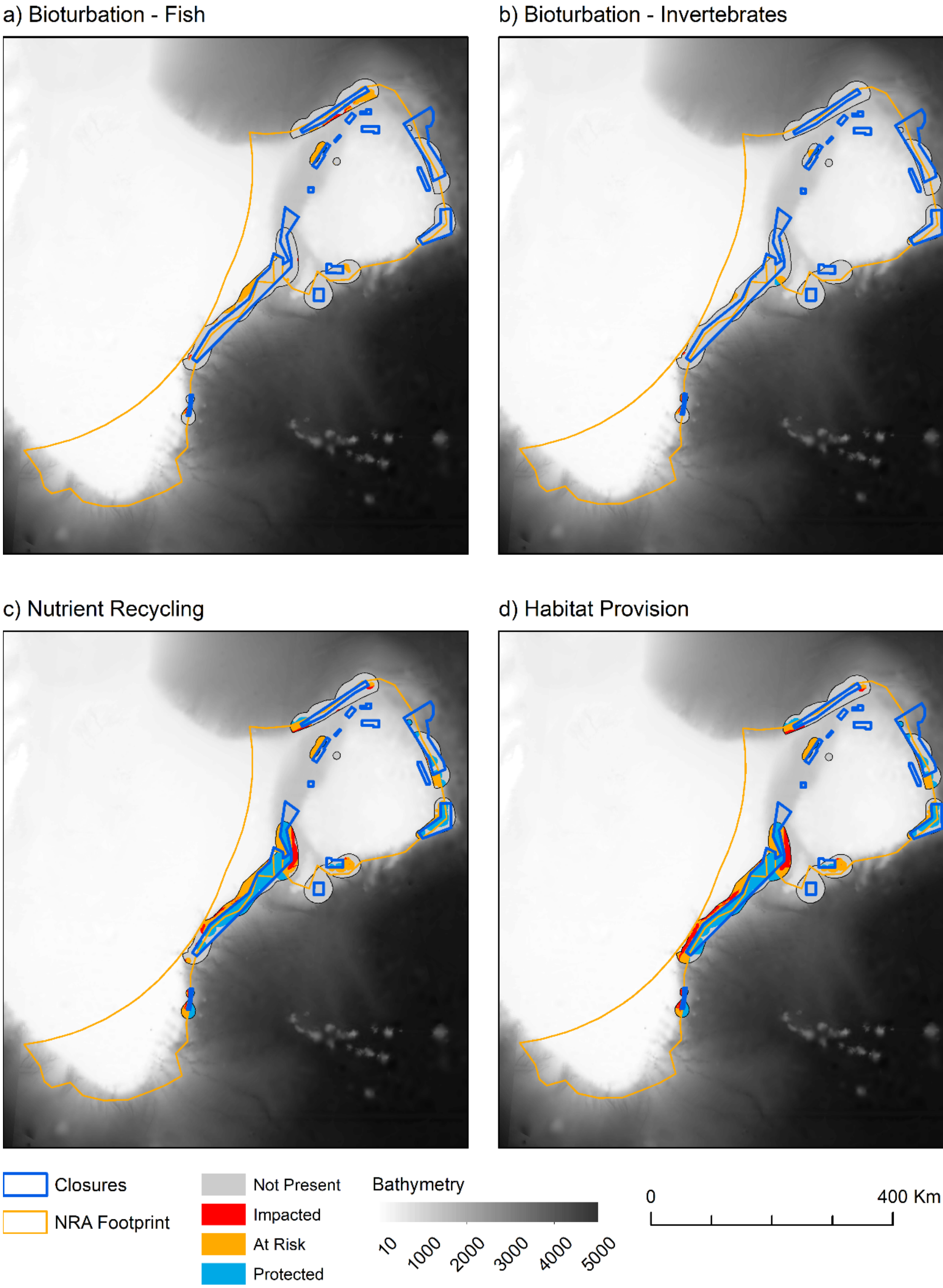


Figure 7.74. Functional groups inside the sponge VME classified impacted, at risk and protected, with the boundaries of the NRA fishing footprint and fisheries closures.

Summary table of functional groups overlapping with VMEs, area impacted, at risk and protected and as a % of the total VME area (km^2).

When comparing the proportion of the overlap of the four functional types with the VME polygons, it is apparent that some VME types only overlap specific functions with any level of significance, whereas other VMEs appear to equally overlap all functions (Table 7.40). For example, the bryozoan VME and to a lesser extent the sea pen and black coral VMEs, appear to significantly overlap all the assessed functions, whereas the large gorgonian and sponge VMEs only significantly overlap the nutrient cycling and habitat provision functions. The number of functions overlapping with a VME with a spatial extent >50% in unprotected VME areas provides a potential indicator of VME functional SAI risk. For example, an area of VME 'at risk' which supports a greater number of functions would potentially be at greater risk of SAI than an area of VME 'at risk' which support fewer functions. In the present assessment, and based upon the results presented in Table 7.40, the VME functional SAI risk is; sponge = 2 (low risk), sea pen = 4 (high risk), large gorgonian = 2 (low risk), small gorgonian = 1 (low risk), black coral = 3 (intermediate risk), bryozoan = 4 (high risk), sea squirt = 4 (high risk).

Table 7.40. Summary table of functional groups overlapping with VMEs, area (km²) impacted, at risk and protected and as a % of the total VME area.

Function	SAI metric	VME						
		Sponge	Sea pen	Large gorgonian	Small gorgonian	Black Coral	Bryozoan	Sea Squirt
Bioturbation - Fish	% VME overlap	11%	54%	3%	27%	59%	100%	94%
	Not present	21,679 (89%)	3,938 (46%)	4,858 (97%)	3,295 (73%)	1,090 (41%)	8 (0%)	256 (6%)
	Protected	200 (1%)	519 (6%)	9 (<1%)	21 (<1%)	216 (8%)	0 (0%)	16 (<1%)
	At Risk	2,164 (9%)	3,809 (45%)	146 (3%)	449 (10%)	1,319 (50%)	3,389 (97%)	3,523 (86%)
	Impacted	188 (1%)	229 (3%)	3 (0%)	776 (17%)	7 (0%)	101 (3%)	285 (7%)
Bioturbation - Invertebrates	% VME overlap	4%	52%	2%	41%	45%	96%	79%
	Not Present	23,362 (96%)	4,058 (48%)	4,925 (98%)	2,687 (59%)	1,177 (45%)	131 (4%)	839 (21%)
	Protected	287 (1%)	582 (7%)	35 (1%)	48 (1%)	185 (7%)	5 (<1%)	16 (<1%)
	At Risk	546 (2%)	3,768 (44%)	54 (1%)	1,520 (33%)	1,245 (47%)	3,236 (93%)	2,998 (73%)
	Impacted	36 (<1%)	87 (1%)	2 (0%)	286 (6%)	25 (1%)	126 (4%)	227 (6%)
Nutrient Cycling	% VME overlap	52%	54%	75%	12%	59%	96%	97%%
	Not Present	11,590 (48%)	3,936 (46%)	1,243 (25%)	4,017 (88%)	1,085 (41%)	139 (4%)	112 (3%)
	Protected	6,981 (29%)	1,036 (12%)	2,279 (45%)	212 (5%)	294 (11%)	5 (<1%)	16 (<1%)
	At Risk	4,740 (20%)	2,983 (35%)	1,212 (24%)	274 (6%)	1,131 (43%)	2,897 (83%)	3,466 (85%)
	Impacted	919 (4%)	540 (6%)	282 (6%)	212 (5%)	122 (5%)	457 (13%)	486 (12%)
Habitat Provision	% VME overlap	*58%*	76%	77%	62%	68%	61%	98%
	Not Present	*10,192 (42%)*	2,008 (24%)	1,178 (23%)	1,740 (38%)	849 (32%)	1,360 (39%)	100 (2%)
	Protected	7,622 (31%)	1,165 (14%)	2,282 (45%)	54 (1%)	373 (14%)	5 (<1%)	16 (<1%)
	At Risk	4,739 (20%)	4,071 (48%)	1,136 (23%)	1,881 (41%)	1,270 (48%)	1,445 (41%)	2,752 (67%)
	Impacted	1,678 (7%)	1,251 (15%)	420 (8%)	866 (19%)	140 (5%)	688 (20%)	1,212 (30%)

x) *Additional SAI assessment metrics*

Fishing stability index

An analysis was performed to determine the spatial stability of the commercial fishing effort using VMS data observed within each VME polygon over a 10-year time span between 2010 and 2019. A geographic information system (GIS) analysis was conducted to calculate the frequency and percentage of each VME that has been fished above the defined VME specific impact cut-off threshold (as described in section 7.d)iii), as a proportion of the total area of the VME that has been fished above the threshold for at least one year (excluding any effort within closed 'protected' areas).

Annual VMS fishing effort data along with the VME polygons for black corals, *boltenia* sp., bryozoans, large gorgonians, sea pens, small gorgonians, and sponges and their associated fishing impact cut-off values served as input for this analysis (see section 7.d)iii for details of the input data layers used in this analysis).

The first step in this analysis was to create annual fishing effort layers for each of the VMEs. This was achieved by performing a clip analysis to trim each of the 10 annual fishing layers to the VME polygon boundaries (Figure 7.75). This process was repeated for each VME polygons against the 10 annual fishing effort layers to create annual, VME-specific, effort layers.

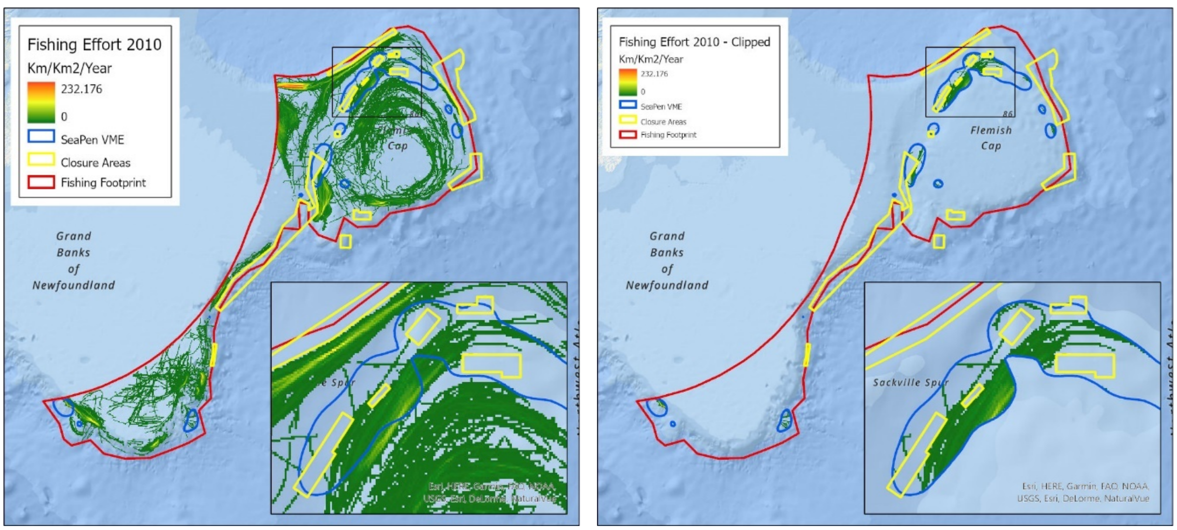


Figure 7.75. Left panel showing the 2010 commercial fishing effort for the entire NRA and the extent of the sea pen VME polygon (inset a zoomed part of the NRA). The right panel depicts the effort clipped to the sea pen VME polygon for the same year.

Analysis presented in section 7.d)iii, calculated the level of fishing effort, expressed in km/km^2/year, at which a VME was considered to have been impacted. These values were used as the cut-off thresholds to identify the regions of the clipped effort layers that were considered to be impacted.

Identifying the impacted regions of the annual VME effort layers was accomplished using the reclassify function in ARC GIS. This function reclassifies, or changes, the values based on a user-provided break-point(s). For each of the VME clipped effort layers, any effort that was below its associated cut-off threshold was changed to a 0 while any effort, at or above the threshold, was reclassified as 1. Figure 7.76 illustrates how the clipped effort for sea pen in 2010 was reclassified to identify the impacted areas outside of closed areas (shown in red) above the sea pen impact threshold value. This was process repeated for each annual fishing effort layer, for each VME.

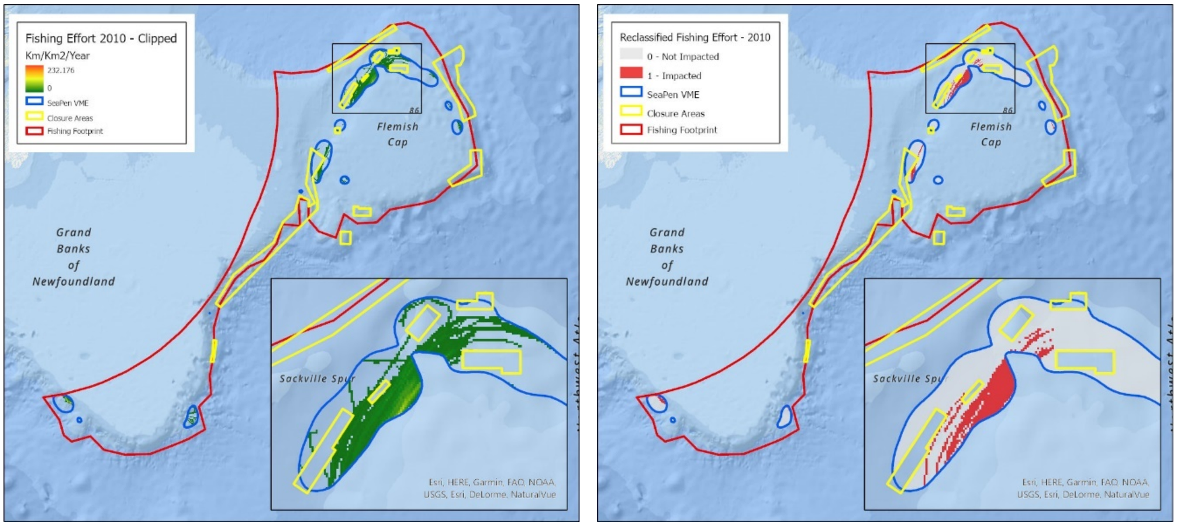
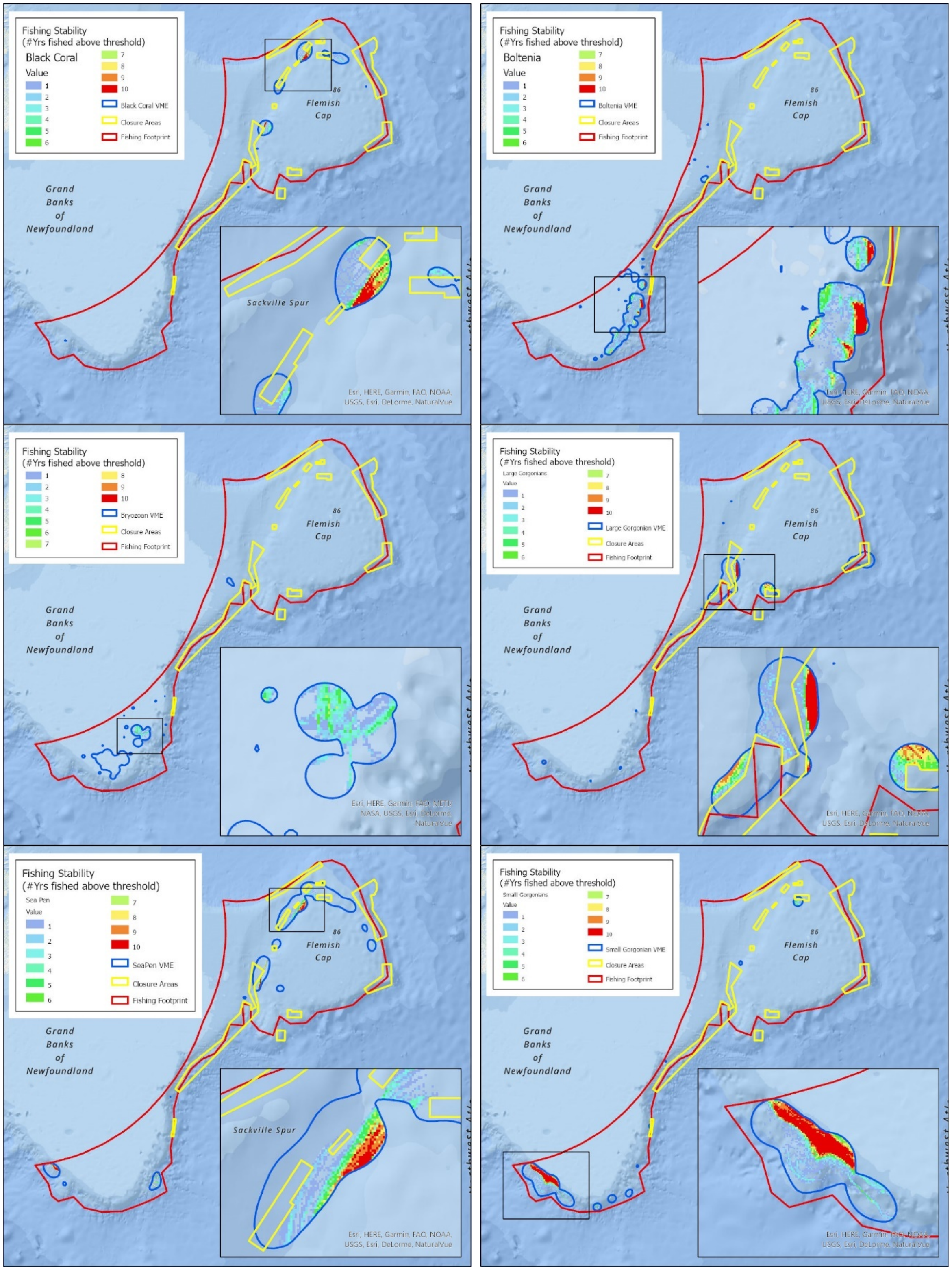
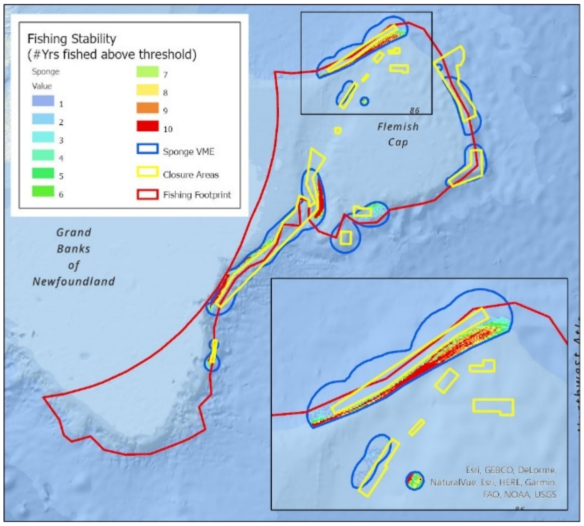


Figure 7.76. Left panel illustrates the original clipped effort layers. Right panel shows the areas above the effort cut-off value (impacted state) shown in red, and the areas below the cut-off value (unimpacted state) shown in grey. The unimpacted state includes areas both fished below the cut-off value and areas unfished.

For each VME, this analysis created 10 fishing effort layers (one for each year analysed) which identified the impacted regions at or above the impact cut-off value. These 10 layers were then analysed using the cell statistics function in ARC GIS to identify the cells which were fished at or above the cut-off value and how frequently the cells were fished at this level over the entire 10-year times series. A value of 1 in the resulting combined layer, indicates that an area was fished once in the 10-year period, while a 10 denotes that the area was fished every year for the 10-year period. The regions of the VME that were never impacted at or above the cut-off value were excluded from the fishing effort layer. The resulting maps are shown in figures 7.77 to 7.83.


Fishing Stability
(#Yrs fished above threshold)
Black Coral
Value
Black Coral VME
Closure Areas
Fishing Footprint
Flemish Cap
Grand Banks of Newfoundland
Sackville Spur
Fishing Stability
(#Yrs fished above threshold)
Boltenia
Value
Boltenia VME
Closure Areas
Fishing Footprint
Fishing Stability
(#Yrs fished above threshold)
Bryozoan VME
Closure Areas
Fishing Footprint
Fishing Stability
(#Yrs fished above threshold)
Large Gorgonians
Value
Large Gorgonian VME
Closure Areas
Fishing Footprint
Fishing Stability
(#Yrs fished above threshold)
Sea Pen
Value
SeaPen VME
Closure Areas
Fishing Footprint
Sackville Spur
Fishing Stability
(#Yrs fished above threshold)
Small Gorgonians
Value
Small Gorgonian VME
Closure Areas
Fishing Footprint



Figures 7.77 to 7.83. Result of the cell statistics summation analysis for each VME. The areas are classified to reflect fishing stability represented by the number of years each raster cell was fished at or above the impact cut-off value.

Using the areas extracted from the fishing stability layers, the proportion of the area for each of the years investigated (above the cut-off value for each VME) was calculated as a fraction of total area and total effort, fished at or above the impact cut-off level for at least one year. The results of this analysis are show in Table 7.41 and Table 7.42, respectively. The value used for the overall assessment of SAI (see Section 7.d)xi)

Table 7.41. The fraction of VME area fished at or above the cut-off level associated with the number of years consistently impacted.

# Years Impacted	Sponge		Small Gorgonians		Sea Pens		Large Gorgonians		Bryozoans		Boltenia		Black Coral	
	Area (km²)	% VME	Area (km²)	% VME	Area (km²)	% VME	Area (km²)	% VME	Area (km²)	% VME	Area (km²)	% VME	Area (km²)	% VME
1	1,595	24.4%	559	25.4%	587	31.3%	444	28.9%	211	33.2%	853	35.1%	506	37.8%
2	885	13.5%	309	14.0%	302	16.1%	183	11.9%	129	20.3%	479	19.7%	201	15.0%
3	605	9.2%	157	7.1%	157	8.4%	101	6.6%	119	18.7%	307	12.6%	143	10.7%
4	471	7.2%	101	4.6%	101	5.4%	85	5.5%	100	15.7%	184	7.6%	79	5.9%
5	361	5.5%	79	3.6%	101	5.4%	72	4.7%	42	6.6%	124	5.1%	57	4.3%
6	331	5.1%	87	3.9%	75	4.0%	87	5.7%	22	3.5%	109	4.5%	75	5.6%
7	278	4.2%	64	2.9%	85	4.5%	100	6.5%	8	1.3%	77	3.2%	51	3.8%
8	308	4.7%	77	3.5%	97	5.2%	118	7.7%	4	0.6%	70	2.9%	42	3.1%
9	394	6.0%	162	7.4%	170	9.1%	111	7.2%		0.0%	64	2.6%	47	3.5%
10	1,319	20.1%	609	27.6%	203	10.8%	237	15.4%		0.0%	161	6.6%	137	10.2%
Totals	6,547	100%	2,204	100%	1,878	100%	1,538	100%	635	100%	2,428	100%	1,338	100%

Table 7.42. The fraction of VME fishing effort at or above the fishing impact cut-off level associated with the number of years consistently impacted. The results used for the overall assessment of SAI (see Section 7.d)xi) are highlighted in grey.

# Years Impacted	Sponge		Small Gorgonians		Sea Pens		Large Gorgonians		Bryozoan		Boltenia		Black Coral	
	Effort	% VME	Effort	% VME	Effort	% VME	Effort	% VME	Effort	% VME	Effort	% VME	Effort	% VME
1	1,739	1%	4,335	1%	8,451	7%	564	1%	6,327	18%	5,233	6%	809	4%
2	2,340	1%	4,117	1%	6,972	6%	525	1%	5,820	17%	5,238	6%	846	4%
3	2,899	1%	3,210	1%	5,051	4%	585	1%	6,949	20%	5,897	7%	914	4%
4	3,864	1%	2,960	1%	4,412	3%	871	1%	7,346	21%	4,913	6%	718	3%
5	4,292	1%	3,296	1%	5,606	4%	1,730	2%	4,403	13%	4,669	5%	928	4%
6	6,322	2%	4,595	1%	4,904	4%	5,511	6%	2,260	7%	7,506	9%	1,593	7%
7	7,290	2%	4,030	1%	6,621	5%	11,599	13%	919	3%	5,924	7%	1,210	5%
8	11,139	3%	7,958	2%	10,529	8%	13,597	15%	583	2%	6,458	7%	1,359	6%
9	19,228	6%	33,164	10%	24,853	20%	14,069	16%	0	0%	7,598	9%	2,225	10%
10	274,479	82%	277,194	80%	49,198	39%	38,864	44%	0	0%	34,053	39%	12,230	54%
Totals	333,592	100%	344,859	100%	126,598	100%	87,916	100%	34,606	100%	87,490	100%	22,834	100%

Overlapping VME index

A secondary SAI metric used in the 1st assessment of SAI used the proportion of overlapping VMEs associated with VME closures as an index of potential VME significance, such that a VME closure which supports several VME types would potentially have greater ecological significance or VME 'richness' than a closure consisting of one VME type. Accordingly, several VME overlap indices have been developed to map and quantify areas of VME overlap. Presented here are five (5) separate indices (three (3) local and two (2) global) providing different approaches and measures of how to examine overlapping VMEs. Figure 7.84 displays all current VME polygons in the area of interest.

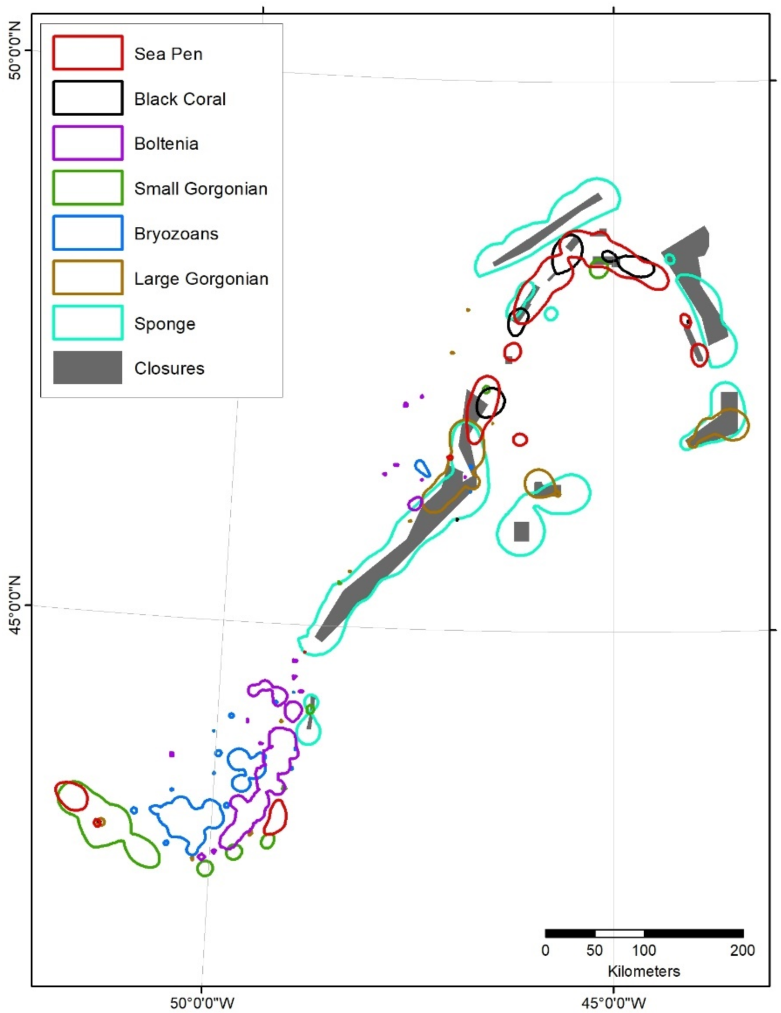


Figure 7.84. Spatial distribution of all VME polygons.

All index calculations utilized a single GIS layer containing polygons representing the count of overlapping VME polygons (referred to as the VME overlap layer). To generate this layer each of the VME polygons were merged into a single layer and then used as input into the 'count overlapping features' tool in ArcPro v.2.5.0 (Figure 7.85). The number of overlapping VME polygons ranged from 1 to 4 (1 representing no overlap). The layer was queried to give overlap counts >= 2, thereby representing all areas of VME overlaps which amounted to 7,370.4 km^2.

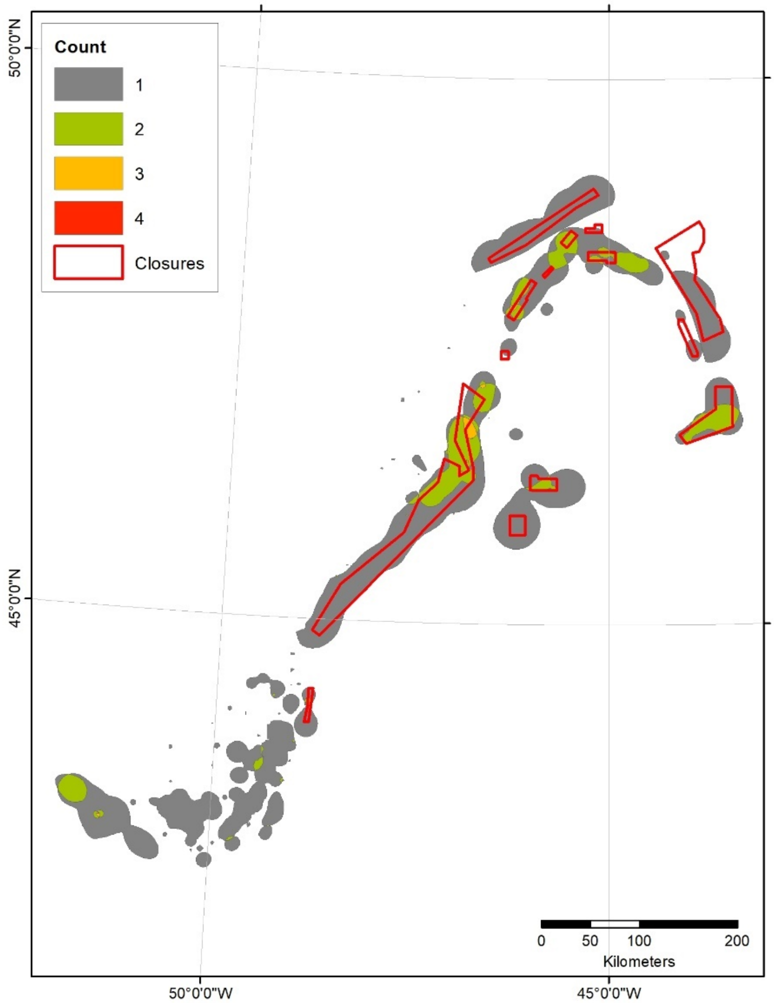


Figure. 7.85. VME overlap layer (VME_O). Polygons representing count of overlapping VME polygons generated using the 'count overlapping features' tool in ArcPro v2.5.0. Gray area indicates the total area of VME (VME_N)

All five indices were calculated using different combinations of four polygon layers; individual VME layers (VME_i), the VME overlap layer (VME_O), total area of all VMEs (VME_N), and the closures layer (Closures). Indices 1 to 3 provided index values for each VME type and so can be considered local indices, while indices 4 and 5 each resulted in one index value for the entire area providing a global index. The index calculations are as follows:

1. $(VME_i \cap VME\_O) \div VME_i$
2. $(VME_i \cap VME\_O) \div VME\_O$
3. $(VME_i \cap (VME\_O \cap Closures)) \div (VME_i \cap VME\_O)$
4. $VME\_O \div VME_N$
5. $(VME\_O \cap Closures) \div VME\_O$

where, VME_i = total area of VME_i, VME_O = total area of VME overlap count >= 2, VME_N = total area of all VMEs, and Closures = total area of closure polygons.

The numerator for index 1 and 2 was generated by using the spatial intersect tool (Figure 7.86) in ArcPro v2.5.0, which calculated the intersection between each VME and the VME overlap layer. Areas of the resulting layers were generated and used in the formulas. The spatial intersect tool was used three times for index 3; first generating the intersection between the VME overlaps layer and the closures layer, then taking the output and intersecting with VME_i, and finally intersecting VME_i with the VME overlap layer (VME_O) to calculate the denominator. Index 4 used the total footprint area of all VMEs which was generated by merging (using the merge tool) all of the VME layers together and aggregating them (using the dissolve tool) into one single layer representing the area of all VMEs.

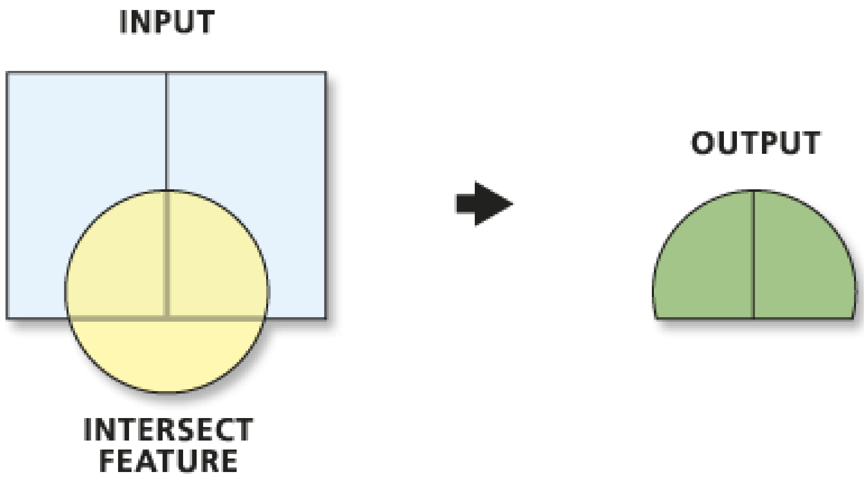


Figure 7.86. Spatial intersect (pro.arcgis.com)

Table 7.43 and Table 7.44 present the results for local indices 1 to 3 using area (km^2) and biomass (kg) values, respectively. For each respective VME the 'overlap' is the intersection between the VME and VME overlaps layer, while 'overlap closure' is the intersection between the VME overlap layer and the closures layer which is then intersected with the VME of interest.

Table 7.43. Local overlap indices for each VME area (km^2). S: sponges, SG: small gorgonians, sp: sea pens, lg: large gorgonians, bz: bryozoan, bt: boltenia, bc: black coral.

ID	Area	Overlap	Overlap Closure	Overlap / Area	Overlap / VME_O	Overlap Closure / Overlap
				Index 1	**Index 2**	**Index 3**
S	24,217.84	4,311.67	2,668.61	17.8%	58.5%	61.9%
SG	4,540.22	885.90	80.26	19.5%	12.0%	9.1%
SP	8,497.60	3,435.18	645.25	40.4%	46.6%	18.8%
LG	5,006.60	3,992.93	2,581.13	79.8%	54.2%	64.6%
BZ	3,491.45	114.00	5.02	3.3%	1.5%	4.4%
BT	4,076.72	172.87	-	4.2%	2.3%	0.0%
BC	2,631.08	2,108.63	434.82	80.1%	28.6%	20.6%

Table 7.44. Local overlap indices for each VME biomass (kg). S: sponges, SG: small gorgonians, sp: sea pens, lg: large gorgonians, bz: bryozoan, bt: boltenia, bc: black coral.

ID	Biomass	Overlap	Overlap Closure	Overlap / Biomass	Overlap / VME_O	Overlap Closure / Overlap
				Index 1	**Index 2**	**Index 3**
S	277,889,468.59	38,564,816.01	38,052,610.34	14%	99%	99%
SG	3,325.28	446.77	40.23	13%	<1%	9%
SP	88,682.11	41,075.54	17,295.89	46%	0%	42%
LG	124,004.14	109,108.09	89,801.16	88%	<1%	82%
BZ	65,545.60	149.06	4.81	0%	0%	3%
BT	41,558.80	213.46	0	0%	<1%	0%
BC	9,609.75	9,115.21	2,133.33	22%	0%	23%

Index 1 can be interpreted as the percentage of each VME that has some overlap with at least one other VME. Index 2 is the percentage the VME overlap that occurs in the VME. Finally, Index 3 provides the percentage overlap of each VME that occurs inside VME closures. Large gorgonians and black coral have high proportions (~80%) of their area with VME overlaps, indicating that these VMEs are highly associated with other VME types. Sponge, sea pens, and large gorgonians all intersect with roughly half of the VME overlap area. *Boltenia* sp. and bryozoan have very little area with VME overlap, indicating their relative spatial independence from other VME types. In reference to closures, roughly 60% of the VME overlaps in sponge and Large Gorgonians occur inside closures, all other VMEs are 20% or less.

Index 4 was calculated as 16.4%, meaning approximately 16% of the total area of all VMEs had some level of overlap. Index 5, which indicates the percent of the VME overlaps inside closures, was calculated to be 42.9%.

For the purpose of the current assessment of SAI the index representing the proportion of VME area/biomass overlap within VME closures (Index 3) provides an indication of the risk of SAI, *e.g.,* the SAI risk is considered to be lower for a VME which has a relatively large proportion of its biomass overlapping with other VMEs within a protected area.

Isolation/Proximity Index as a measure of VME fragmentation

Habitat fragmentation is a global concern affecting both terrestrial and marine ecosystems (Wilson *et al.*, 2016) and has been linked to extinction risk and biodiversity loss (Crooks *et al.*, 2017), often mediated through changes in community composition, trophic structure, species persistence and residency. Defined as the division of habitat into smaller and more isolated fragments (Haddad *et al.*, 2015), habitat fragmentation can arise through both natural and anthropogenic activities. The latter have been shown to alter habitat quality and connectivity (Haddad *et al.*, 2015; Wilson *et al.*, 2016) and in the context of our work within NAFO most directly relate to the impacts of bottom contact fishing gears on Vulnerable Marine Ecosystems (VMEs), although the area could also be impacted by oil spills and related human activities that could cause spatially heterogeneous mortality.

NAFO has used kernel density analyses to identify VMEs dominated by large-sized sponges, sea pens, small and large gorgonian corals, erect bryozoans, sea squirts (*Boltenia ovifera*), and black corals (Kenchington *et al.*, 2019). That analysis (Kenchington *et al.*, 2014) generates polygons of significant concentrations of biomass for each VME indicator which are spread across the spatial domain of the NAFO fishing footprint. There is potential for bottom contact fishing to induce changes in both the amount and configuration of habitat (*e.g.*, decreased polygon size, increased polygon isolation, and increased edge area) through direct and indirect impacts, and while it is unknown the exact degree to which such changes may already have taken place given the long fishing history of the area, analyses of the overlap of fishing and VMEs in Canadian waters (Koen-Alonso *et al.*, 2018), and initial modelling results focused on sea pens (NAFO, 2020; this report) suggest that these historical impacts can be expected to be important.

Going forward WG-ESA has explored methods and indices that could be used to identify changes in the spatial configuration of the landscape caused by fishing activity. We have focussed initially on indices of isolation, or its converse, proximity, as commonly used in spatial ecology (Fortin and Dale, 2005; Maguire *et al.*, 2005), as other metrics related to size and edge area of the polygons are subject to some change due to the spatial configuration of the input data (Kenchington *et al.*, 2019), making it difficult to determine whether change is do to changes in the input data or to human-induced fragmentation.

Distance Measurements

We used the 'Proximity Analysis' tools in ArcGIS 10.7 applied to all VME polygons and to the closed areas to generate our results. Two methods were used to calculate nearest neighbour distances between polygons: centroid to centroid, and edge to edge. For the first, a centroid was calculated for each polygon using the 'Feature to Point' tool in ArcGIS, with the 'Inside' option to ensure that the centroid is inside the polygons. Then the 'Point Distance' tool was used to calculate the Euclidean distance and generate the proximity matrix between all pairs of VME polygons (Figure 7.87, left panel). We then performed the same analyses using the 'Generate Near Table' tool to calculate the distances from the nearest edges of the polygon pairs to calculate the distances (Figure 7.87, right panel), recognizing that the configuration of some polygons was elongated and so the centroid although more stable, was not as representative of closest distances, which are of relevance to fragmentation processes acting through connectivity.

Isolation/Proximity Indices

Isolation (or proximity) refers to the tendency for polygons to be relatively isolated in space from other polygons. If d*ij* is the nearest-neighbour distance from polygon *i* to another polygon *j* of the same type, then the **mean nearest-neighbour distance over all polygons** is a measure of relative isolation. This was calculated for both distance methods.

The 'Average Nearest Neighbour' tool averages all the nearest neighbour distances using the centroids of each polygon, to create an index of isolation/proximity: "If the average distance is less than the average for a hypothetical random distribution, the distribution of the features being analyzed is considered clustered. If the average distance is greater than a hypothetical random distribution, the features are considered dispersed. The **average nearest neighbour ratio** is calculated as the observed average distance divided by the expected average distance (with expected average distance being based on a hypothetical random distribution with the same number of features covering the same total area)" https://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/h-how-average-nearest-neighbor-distance-spatial-st.htm. Although the distribution of VME polygons is expected to be non-random, changes in the **average nearest neighbour ratio** towards increased clustering can indicate fragmentation.

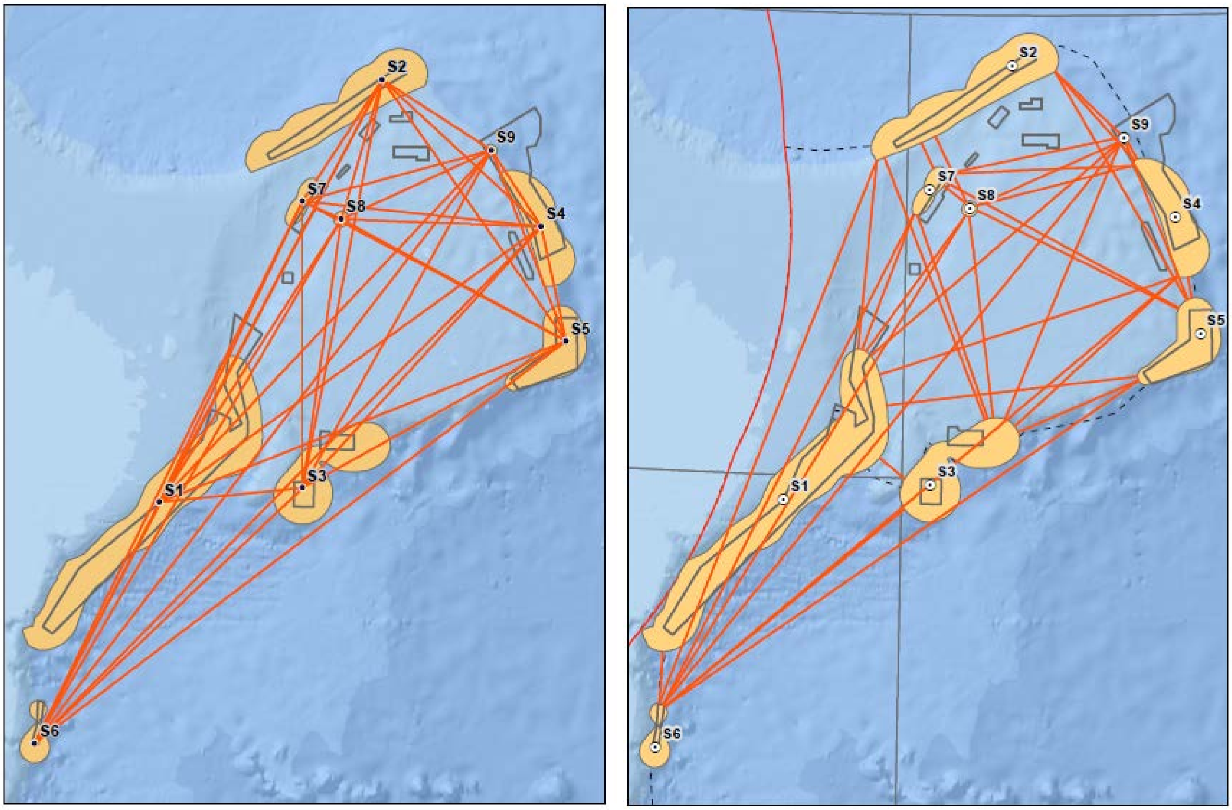


Figure 7.87. Nearest neighbour distance lines between large-sized sponge VME polygons in the NRA calculated from centroid to centroid (Left panel) and from the nearest edge (Right panel). NAFO Closed Areas for the protection of corals and sponges are indicated in grey.

For the edge-to-edge distances we calculated a proximity index (PX) described by Gustafson and Parker (1994), which quantifies the spatial context of a habitat patch in relation to its neighbours. The index distinguishes sparse distributions of small habitat patches from clusters of large patches and is calculated using the edge-to-edge distances such that:

$$PX = \sum_{i=1}^{n} (\frac{S_i}{z_i})$$

Where S is the area of polygon i, z is the edge-to-edge distance from patch i to its nearest-neighbour patch of each of the n polygons. PX is large when the polygon is surrounded by larger and/or closer polygons and decreases as polygons become smaller and/or sparser (Gustafson and Parker, 1994). Manipulations of their data sets showed that reducing the isolation of patches within the same spatial extent produced exponential change in PX, while just an increase in the size of those patches produced a more modest linear increase in PX, suggesting that PX is a good measure for detecting fragmentation (Gustafson and Parker, 1994). Simulation work showed that the spatial extent used to undertake the calculations (*i.e.*, the number of patches included) produced linear increases in PX with the slope being dependent on the proportion of the habitat of interest on the landscape (Gustafson and Parker, 1994); therefore, there is no bias in PX when applied to the scale of the NRA.

These indicators were calculated for each of the NAFO VME indicators using the 2019 VME polygons (Kenchington *et al.*, 2019). We also applied them to the closed areas in order to evaluate the closed area network in terms of relative configuration to the VME polygons.

Application to Large-Size Sponge VME Polygons

The results of the analyses are shown in Table 7.45 and Table 7.46. The distances between sponge polygons ranged from 34 to 600 km centroid to centroid, and 14 to 565 km edge-to-edge. Using the distances from centroid to centroid, shown in the lower diagonal of Table 7.45, the values for the mean nearest-neighbour distance over all polygons and the average nearest neighbor ratio are provided in Table 7.46. The values for the mean nearest-neighbour distance over all polygons and PX are provided for the edge-edge distances (Table 7.46).

Table 7.45. Nearest neighbour distances (km) calculated from centroid to centroid (below diagonal, shaded) and from nearest edges (above diagonal) for the sponge VME polygons in the NRA (numbered as in Figure 7.87). The mean nearest-neighbour distance for each polygon, as a measure of relative isolation, is shown below the rows for the centroid-to-centroid distances and to the right of columns for the nearest edges distances. Polygons are numbered according to decreasing area.

	Polygon Area (km²)	S1	S2	S3	S4	S5	S6	S7	S8	S9	Mean Nearest-Neighbour Distance (Edge-Edge)
S1	9687.0	---	148	25	244	197	40	113	131	256	144
S2	4596.9	382	---	219	93	205	455	22	56	69	158
S3	3695.9	115	333	---	172	102	242	168	157	234	165
S4	2571.5	377	173	283	---	17	521	144	125	14	166
S5	2255.1	350	256	242	94	---	448	206	175	131	185
S6	711.9	217	600	296	579	534	---	429	448	565	394
S7	516.2	267	116	230	192	239	484	---	21	136	155
S8	119.8	269	116	217	160	205	486	34	---	122	154
S9	63.5	387	104	310	73	164	599	157	132	---	191
Mean Nearest-Neighbour Distance (Centroid-Centroid)		296	260	253	241	261	474	215	202	241	

The observed mean distance among sponge VME polygons (centroid to centroid) is 95.54 km and the expected mean distance based on a random distribution is 62.84 km. The observed distribution is significantly different from the expected distribution, indicating that the polygons have greater dispersion than by chance alone. In this context this is not surprising given the strong role environmental filtering plays in determining species' distributions. For the calculations from the edges rather than the centroids (Table 7.45) the mean nearest-neighbour distance is smaller, as expected (Table 7.46) and the proximity index PX was calculated. Both of these isolation/proximity indices can be used to evaluate fragmentation.

Table 7.46. Isolation/Proximity indices for the large-sized sponge VME polygons in the NRA.

Distance Measurement Method	Mean Nearest-Neighbour Distance Over All Polygons Pairs	Nearest Neighbour Ratio	Proximity Index (PX)
Centroid-Centroid	271	1.520512	
Edge-Edge	190		1111.8

Application to Sea Pen VME Polygons

The results of the analyses of the sea pen VME polygons are shown in Table 7.47 and Table 7.48. The distances between sea pen polygons (Figure 7.88) ranged from 37 to 785 km centroid to centroid, and 16 to 775 km edge to edge. Using the distances from centroid to centroid, shown in the lower diagonal of Table 7.47, the values for the mean nearest-neighbour distance over all polygons and the average nearest neighbour ratio are provided in Table 7.48. The values for the mean nearest-neighbour distance over all polygons and PX are provided for the edge-edge distances (Table 7.48).

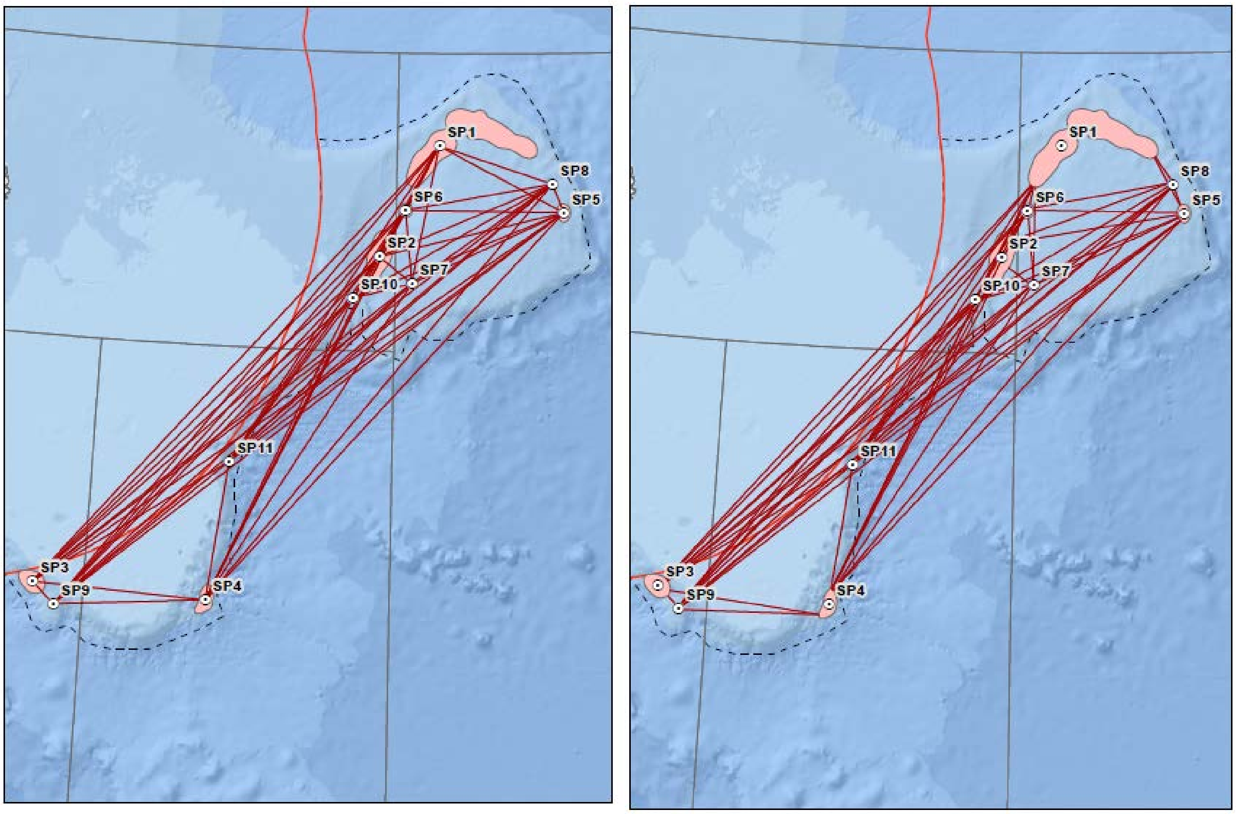


Figure 7.88. Nearest neighbour distance lines between sea pen VME polygons in the NRA calculated from centroid to centroid (Left panel) and from the nearest edge (Right panel). NAFO Closed Areas for the protection of corals and sponges are indicated in grey. Polygons are numbered according to decreasing area.

Table 7.47. Nearest neighbour distances (km) calculated from centroid to centroid (below diagonal, shaded) and from nearest edges (above diagonal) for the sea pen VME polygons in the NRA (numbered as in Figure 7.88). The mean nearest-neighbour distance for each polygon, as a measure of relative isolation, is shown below the rows for the centroid-to-centroid distances and to the right of columns for the nearest edges distances. Polygons are numbered according to decreasing area.

	Polygon Area (km²)	SP1	SP9	SP4	SP3	SP11	SP10	SP7	SP2	SP6	SP5	SP8	Mean Nearest-Neighbour Distance (Edge-Edge)
SP1	5030.1	---	657	539	644	396	150	111	61	20	65	32	268
SP9	34.3	720	---	165	16	268	508	567	536	623	759	775	487
SP4	506.7	616	181	---	181	151	385	432	410	502	608	630	400
SP3	685.8	716	37	208	---	262	497	558	525	610	753	767	481
SP11	0.4	456	272	171	276	---	243	299	270	360	490	506	325
SP10	13.6	212	514	405	513	246	---	64	24	113	262	269	252
SP7	124.4	170	577	456	579	306	73	---	29	74	186	195	252
SP2	1492.8	152	572	465	571	305	60	51	---	24	197	196	227
SP6	228.4	88	635	529	632	369	124	89	64	---	173	165	266
SP5	283.8	169	771	635	775	500	273	201	226	189	---	19	351
SP8	97.3	143	782	652	785	511	276	206	224	178	37	---	355
Mean Nearest-Neighbour Distance (Centroid-Centroid)		344	506	432	509	341	269	271	269	290	377	379	

Table 7.48. Isolation/Proximity indices for the sea pen VME polygons in the NRA.

Distance Measurement Method	**Mean Nearest-Neighbour Distance Over All Polygons Pairs**	**Nearest Neighbour Ratio**	**Proximity Index (PX)**
Centroid-Centroid	363	1.343323	
Edge-Edge	333		394.2

Application to Sea Squirts (Boltenia ovifera) VME Polygons

The results of the analyses of the sea squirt (*Boltenia ovifera*) VME polygons are shown in Table 7.49 and Table 7.50. The distances between sea squirt polygons (Figure 7.98) ranged from 14 to 516 km centroid to centroid, and 2 to 512 km edge to edge. Using the distances from centroid to centroid, shown in the lower diagonal of Table 7.49, the values for the mean nearest-neighbour distance over all polygons and the average nearest neighbour ratio are provided in Table 7.50. The values for the mean nearest-neighbour distance over all polygons and PX are provided for the edge-edge distances (Table 7.50).

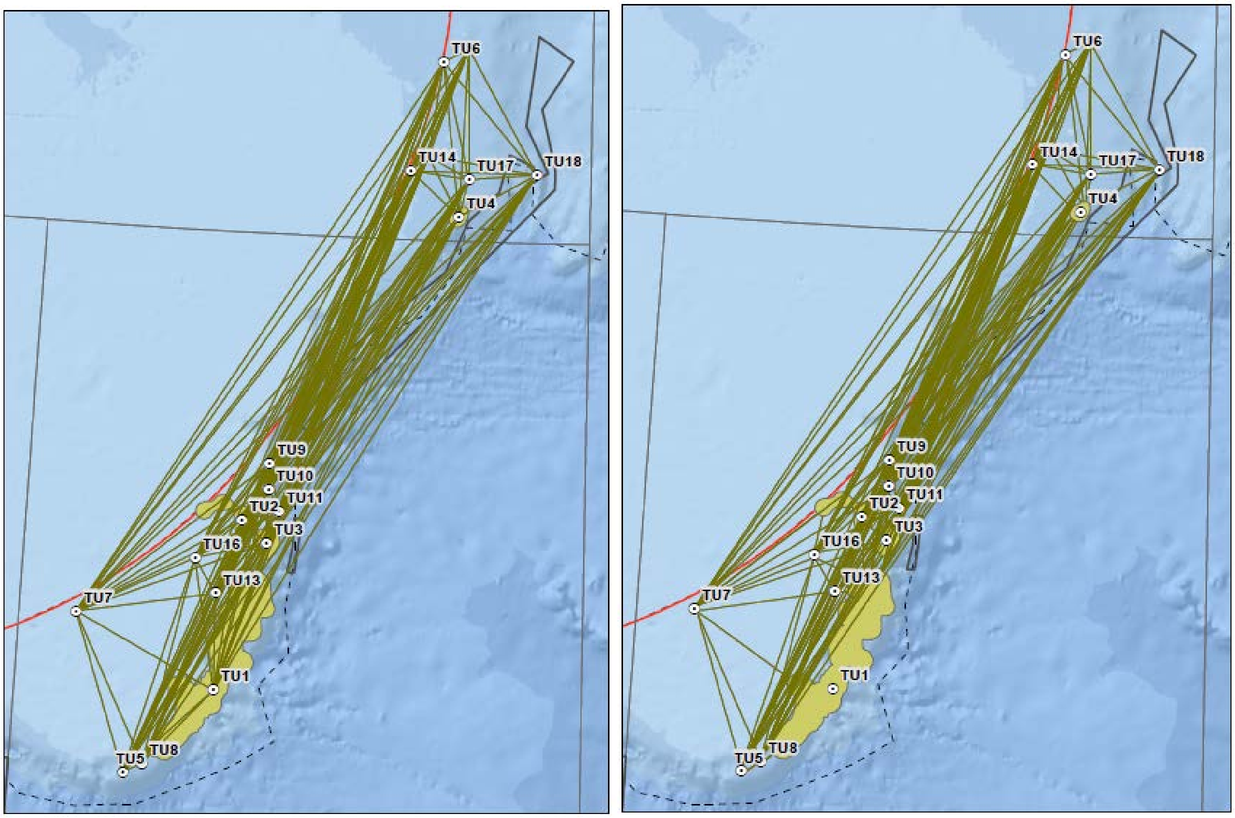


Figure 7.89. Nearest neighbour distance lines between sea squirt VME polygons in the NRA calculated from centroid to centroid (Left panel) and from the nearest edge (Right panel). NAFO Closed Areas for the protection of corals and sponges are indicated in grey. Polygons are numbered according to decreasing area.

Table 7.49. Nearest neighbour distances (km) calculated from centroid to centroid (below diagonal, shaded) and from nearest edges (above diagonal) for the sea squirt VME polygons in the NRA (numbered as in Figure 7.89; T=TU). The mean nearest-neighbour distance for each polygon, as a measure of relative isolation, is shown below the rows for the centroid-to-centroid distances and to the right of columns for the nearest edges distances. Polygons are numbered according to decreasing area.

	Polygon Area (km²)	T1	T5	T8	T7	T13	T16	T3	T2	T11	T10	T9	T4	T14	T17	T18	T12	T6	T15	Mean Nearest-Neighbour Distance (Edge-Edge)
T1	3167.7	---	19	6	73	6	24	9	23	40	51	68	255	275	285	310	288	347	362	144
T5	27.3	79	---	9	103	126	141	161	168	191	200	215	408	425	438	464	438	496	512	266
T8	8.2	66	14	---	103	116	133	151	158	181	190	206	398	416	428	453	429	487	503	257
T7	8.3	102	108	107	---	88	81	120	97	142	143	153	344	353	373	405	367	421	438	224
T13	3.2	62	130	119	90	---	24	36	40	64	72	88	281	298	311	338	311	369	385	174
T16	1.8	86	146	137	84	27	---	38	24	59	61	74	269	283	298	328	296	353	369	168
T3	259.6	101	174	163	130	46	47	---	2	11	23	40	227	246	257	283	259	318	333	148
T2	435.1	111	179	169	122	50	39	22	---	13	15	30	224	240	254	282	253	310	326	145
T11	6.0	122	195	184	145	67	62	22	25	---	13	29	214	233	244	270	246	305	320	151
T10	6.3	134	205	194	146	75	65	35	26	16	---	14	205	222	235	263	235	293	309	150
T9	6.3	150	220	209	156	90	77	51	40	31	16	---	192	207	221	251	220	278	294	152
T4	126.9	343	418	406	353	288	277	243	240	222	214	200	---	36	17	49	37	92	100	197
T14	2.7	358	429	419	356	300	285	257	250	235	224	209	43	---	36	79	12	70	85	207
T17	1.1	367	442	430	375	312	300	268	263	246	237	223	25	38	---	42	28	75	82	213
T18	1.0	391	467	456	408	339	330	294	292	273	266	253	57	81	44	---	68	92	91	239
T12	4.2	370	443	432	370	313	299	270	263	248	238	223	44	15	30	71	---	59	72	213
T6	8.7	431	501	491	425	372	357	330	322	308	297	282	100	73	77	94	61	---	15	258
T15	2.2	444	516	505	441	386	372	343	336	322	311	296	108	87	84	92	74	18	---	270
Mean Nearest-Neighbour Distance (Centroid-Centroid)		219	274	265	230	180	176	164	162	160	159	160	211	215	221	247	221	267	279	

Table 7.50. Isolation/Proximity indices for the sea squirt VME polygons in the NRA.

Distance Measurement Method	Mean Nearest-Neighbour Distance Over All Polygons Pairs	Nearest Neighbour Ratio	Proximity Index (PX)
Centroid-Centroid	212	0.989497	
Edge-Edge	199		801.5

Application to Black Coral VME Polygons

The results of the analyses of the black coral VME polygons are shown in Table 7.51 and Table 7.52. The distances between black coral polygons (Figure 7.90) ranged from 44 to 781 km centroid to centroid, and 27 to 779 km edge to edge. Using the distances from centroid to centroid, shown in the lower diagonal of Table 7.51, the values for the mean nearest-neighbour distance over all polygons and the average nearest neighbour ratio are provided in Table 7.52. The values for the mean nearest-neighbour distance over all polygons and PX are provided for the edge-edge distances (Table 7.52).

Table 7.51. Nearest neighbour distances (km) calculated from centroid to centroid (below diagonal, shaded) and from nearest edges (above diagonal) for the black coral VME polygons in the NRA (numbered as in Figure 7.90). The mean nearest-neighbour distance for each polygon, as a measure of relative isolation, is shown below the rows for the centroid-to-centroid distances and to the right of columns for the nearest edges distances. Polygons are numbered according to decreasing area.

	Polygon Area (km²)	BC1	BC5	BC6	BC8	BC3	BC4	BC7	BC2	Mean Nearest-Neighbour Distance (Edge-Edge)
BC1	882.5	---	721	268	190	132	48	126	21	215
BC5	2.1	743	---	472	537	561	644	779	763	640
BC6	1.2	291	474	---	78	106	194	306	301	246
BC8	0.8	213	539	79	---	27	115	247	227	203
BC3	643.8	169	579	123	44	---	57	201	170	179
BC4	400.0	84	659	209	131	87	---	161	94	188
BC7	1.1	141	781	308	248	216	172	---	60	269
BC2	699.4	66	779	312	240	200	129	81	---	234
	Mean Nearest-Neighbour Distance (Centroid-Centroid)	244	651	256	213	203	210	278	258	

Table 7.52. Isolation/Proximity indices for the black coral VME polygons in the NRA.

Distance Measurement Method		Mean Nearest-Neighbour Distance Over All Polygons Pairs	Nearest Neighbour Ratio	Proximity Index (PX)
Centroid-Centroid		289	2.068074	
Edge-Edge		272		108.9

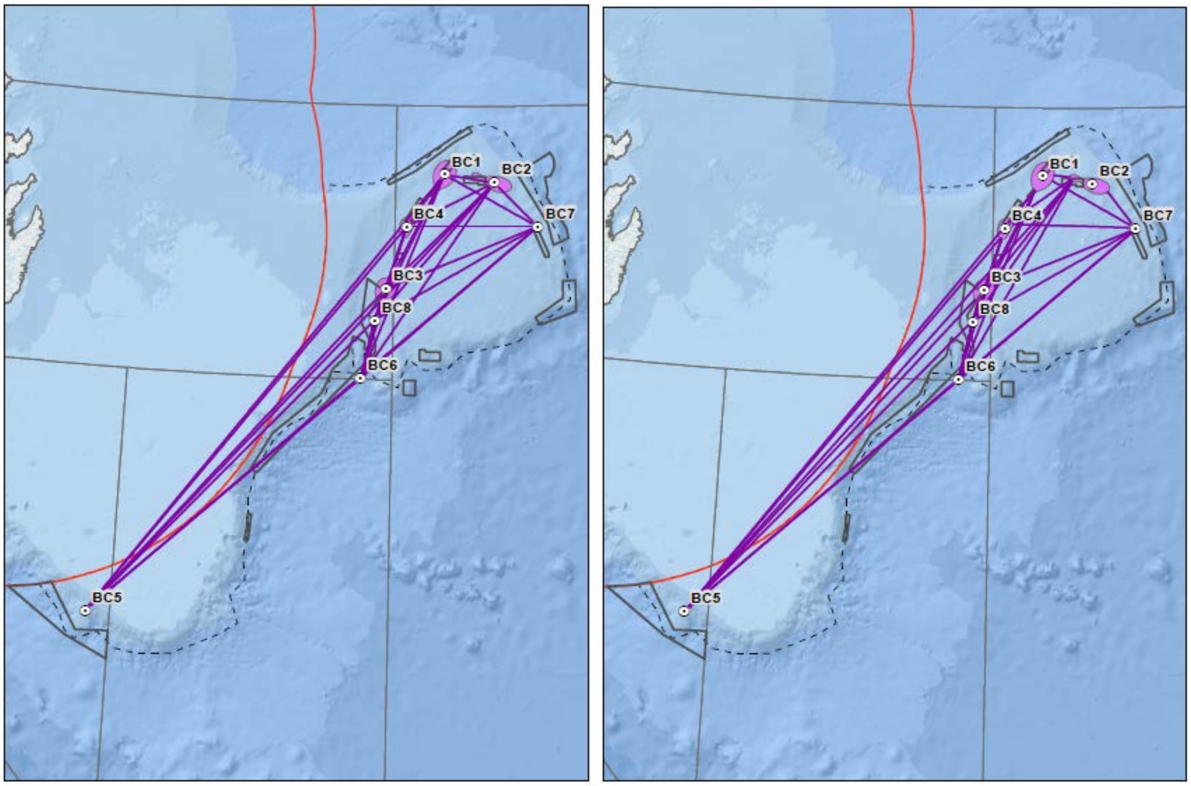


Figure 7.90. Nearest neighbour distance lines between black coral VME polygons in the NRA calculated from centroid to centroid (Left panel) and from the nearest edge (Right panel). NAFO Closed Areas for the protection of corals and sponges are indicated in grey. Polygons are numbered according to decreasing area.

Application to Bryozoan VME Polygons

The results of the analyses of the bryozoan VME polygons are shown in Table 7.53 and Table 7.54. The distances between bryozoan polygons (Figure 7.91) ranged from 20 to 489 km centroid to centroid, and 4 to 486 km edge to edge. Using the distances from centroid to centroid, shown in the lower diagonal of Table 7.53, the values for the mean nearest-neighbour distance over all polygons and the average nearest neighbour ratio are provided in Table 7.54. The values for the mean nearest-neighbour distance over all polygons and PX are provided for the edge-edge distances (Table 7.54).

Table 7.53. Nearest neighbour distances (km) calculated from centroid to centroid (below diagonal, shaded) and from nearest edges (above diagonal) for the bryozoan VME polygons in the NRA (numbered as in Figure 7.91; B=BR). The mean nearest-neighbour distance for each polygon, as a measure of relative isolation, is shown below the rows for the centroid-to-centroid distances and to the right of columns for the nearest edges distances. Polygons are numbered according to decreasing area.

	Polygon Area (km^2)	**B1**	**B7**	**B5**	**B6**	**B12**	**B14**	**B2**	**B13**	**B4**	**B11**	**B15**	**B8**	**B9**	**B17**	**B16**	**B3**	**B10**	**Mean Nearest-Neighbour Distance (Edge-Edge)**
B1	2243.9	---	6	13	4	9	26	22	80	45	94	69	86	116	136	405	392	425	121
B7	13.4	33	---	41	67	51	82	86	144	100	159	120	140	177	197	467	452	486	174
B5	24.2	57	46	---	88	40	86	100	161	97	171	111	133	176	198	465	445	482	175
B6	17.2	40	72	94	---	54	32	16	72	48	87	74	87	112	130	399	387	419	130
B12	2.7	36	54	44	58	---	44	60	121	56	130	72	93	135	156	425	407	443	143
B14	1.9	54	86	89	35	46	---	17	77	16	85	41	57	93	113	383	368	402	120
B2	1006.0	86	119	131	49	88	43	---	26	8	31	27	32	52	69	337	325	357	98
B13	2.4	116	148	165	76	123	79	36	---	72	18	86	78	66	76	331	324	352	130
B4	25.8	74	105	103	53	60	21	41	76	---	74	20	35	73	94	364	347	382	114
B11	4.3	130	162	175	90	132	86	44	20	78	---	83	70	49	56	312	304	333	128
B15	0.5	94	123	114	76	73	43	56	88	23	85	---	21	67	89	354	334	371	121
B8	12.8	114	145	137	91	96	61	58	81	40	73	24	---	43	65	328	310	346	120
B9	5.4	148	180	180	116	137	95	69	69	78	51	69	47	---	19	288	273	306	128
B17	0.3	167	199	201	133	157	115	84	77	98	57	90	67	21	---	269	256	289	138
B16	0.4	437	470	468	401	426	385	352	333	367	314	354	331	290	270	---	44	23	325
B3	125.7	427	459	452	394	412	373	346	331	354	311	339	316	279	261	54	---	41	313
B10	4.6	457	489	486	422	445	404	373	355	386	336	373	349	309	290	25	49	---	341
Mean Nearest-Neighbour Distance (Centroid-Centroid)		154	181	184	138	149	126	123	136	122	134	126	127	134	143	330	322	347	

Table 7.54. Isolation/Proximity indices for the bryozoan VME polygons in the NRA.

Distance Measurement Method	**Mean Nearest-Neighbour Distance Over All Polygons Pairs**	**Nearest Neighbour Ratio**	**Proximity Index (PX)**
Centroid-Centroid	175	1.096139	
Edge-Edge	166		717.1

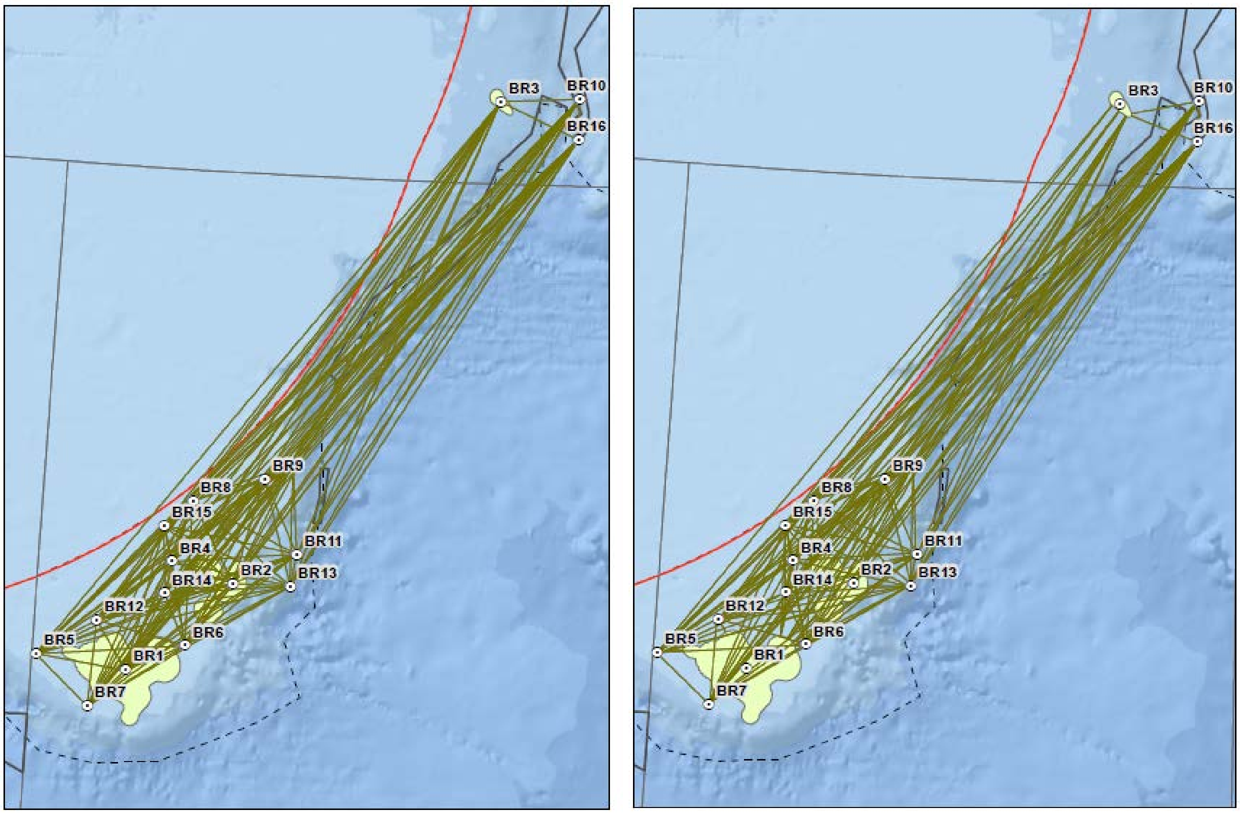


Figure 7.91. Nearest neighbour distance lines between bryozoan VME polygons in the NRA calculated from centroid to centroid (Left panel) and from the nearest edge (Right panel). NAFO Closed Areas for the protection of corals and sponges are indicated in grey. Polygons are numbered according to decreasing area.

Application to Small Gorgonian Coral VME Polygons

The results of the analyses of the small gorgonian coral VME polygons are shown in Table 7.55 and Table 7.56. The distances between small gorgonian coral polygons (Figure 7.92) ranged from 34 to 750 km centroid to centroid, and 17 to 718 km edge to edge. Using the distances from centroid to centroid, shown in the lower diagonal of Table 7.55, the values for the mean nearest-neighbour distance over all polygons and the average nearest neighbor ratio are provided in Table 7.56. The values for the mean nearest-neighbour distance over all polygons and PX are provided for the edge-edge distances (Table 7.56).

Table 7.55. Nearest neighbour distances (km) calculated from centroid to centroid (below diagonal, shaded) and from nearest edges (above diagonal) for the small gorgonian coral (SGC) VME polygons in the NRA (numbered as in Figure 7.92). The mean nearest-neighbour distance for each polygon, as a measure of relative isolation, is shown below the rows for the centroid-to-centroid distances and to the right of columns for the nearest edges distances. Polygons are numbered according to decreasing area.

	Polygon Area (km²)	SGC1	SGC4	SGC3	SGC5	SGC8	SGC6	SGC9	SGC7	SGC2	Mean Nearest-Neighbour Distance (Edge-Edge)
SGC1	3669.3	---	39	68	103	141	205	315	557	718	268
SGC4	182.1	110	---	17	54	104	181	310	550	708	245
SGC3	184.1	133	34	---	20	72	152	283	521	678	226
SGC5	147.0	165	69	36	---	46	128	262	495	651	220
SGC8	10.2	184	114	82	56	---	78	212	446	602	213
SGC6	48.1	237	193	163	140	84	---	126	361	519	219
SGC9	3.1	339	319	292	271	215	131	---	241	401	269
SGC7	33.7	583	561	533	507	452	369	245	---	154	416
SGC2	262.5	750	725	695	668	614	532	412	167	---	554
Mean Nearest-Neighbour Distance (Centroid-Centroid)		313	288	262	250	231	230	269	405	545	

Table 7.56. Isolation/Proximity indices for the small gorgonian coral VME polygons in the NRA.

Distance Measurement Method	**Mean Nearest-Neighbour Distance Over All Polygons Pairs**	**Nearest Neighbour Ratio**	**Proximity Index (PX)**
Centroid-Centroid	311	1.714228	
Edge-Edge	292		125.2

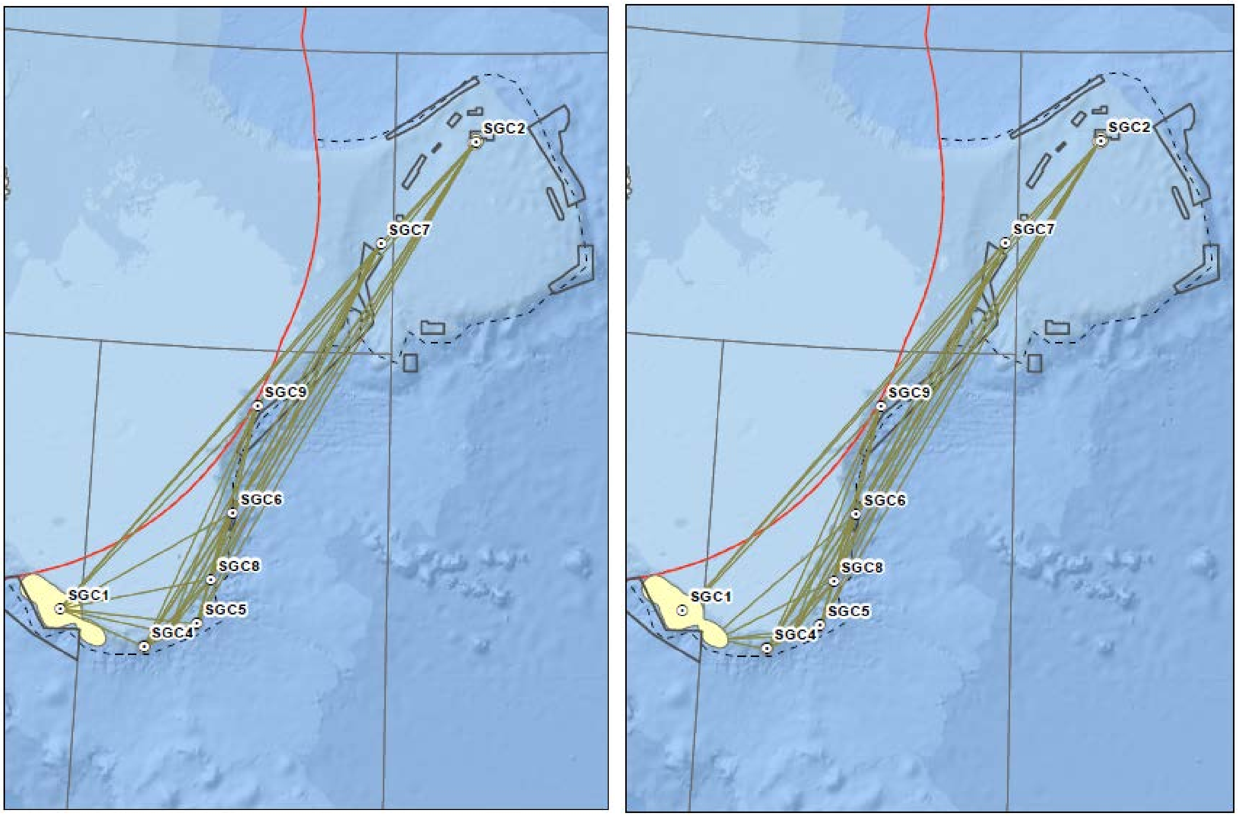


Figure 7.92. Nearest neighbour distance lines between small gorgonian coral VME polygons in the NRA calculated from centroid to centroid (Left panel) and from the nearest edge (Right panel). NAFO Closed Areas for the protection of corals and sponges are indicated in grey. Polygons are numbered according to decreasing area.

Application to Large Gorgonian Coral VME Polygons

The results of the analyses of the large gorgonian coral VME polygons are shown in Table 7.57 and Table 7.58. The distances between large gorgonian coral polygons (Figure 7.93) ranged from 39 to 755 km centroid to centroid, and 13 to 703 km edge to edge. Using the distances from centroid to centroid, shown in the lower diagonal of Table 7.57, the values for the mean nearest-neighbour distance over all polygons and the average nearest neighbour ratio are provided in Table 7.58. The values for the mean nearest-neighbour distance over all polygons and PX are provided for the edge-edge distances (Table 7.58).

Table 7.57. Nearest neighbour distances (km) calculated from centroid to centroid (below diagonal, shaded) and from nearest edges (above diagonal) for the large gorgonian coral (LGC) VME polygons in the NRA (numbered as in Figure 7.93). The mean nearest-neighbour distance for each polygon, as a measure of relative isolation, is shown below the rows for the centroid to centroid distances and to the right of columns for the nearest edges distances. Polygons are numbered according to decreasing area.

	Polygon Area (km^2)	**LGC1**	**LGC6**	**LGC4**	**LGC5**	**LGC8**	**LGC11**	**LGC9**	**LGC3**	**LGC12**	**LGC2**	**LGC7**	**LGC10**	**Mean Nearest-Neighbour Distance (Edge-Edge)**
LGC1	2964.3	---	423	452	369	258	98	19	46	13	207	68	110	188
LGC6	3.1	495	---	94	61	164	329	404	501	533	652	573	619	396
LGC4	41.6	526	99	---	146	204	353	431	542	561	703	588	632	428
LGC5	9.9	442	64	152	---	114	279	351	441	478	589	523	569	356
LGC8	2.3	330	166	209	117	---	165	239	339	368	497	408	455	292
LGC11	0.8	169	331	357	283	166	---	78	196	207	365	242	289	236
LGC9	1.4	90	406	436	354	241	80	---	121	128	291	173	220	223
LGC3	703.8	79	517	560	458	355	212	137	---	62	139	143	175	246
LGC12	0.2	39	535	565	481	369	208	129	78	---	199	81	116	250
LGC2	1274.9	270	701	755	639	546	415	341	204	244	---	254	259	378
LGC7	3.0	104	575	592	527	410	244	175	160	82	293	---	45	282
LGC10	1.2	146	621	637	573	456	290	221	191	117	293	46	---	317
Mean Nearest-Neighbour Distance (Centroid-Centroid)		244	410	444	372	306	250	237	268	259	427	292	326	

Table 7.58. Isolation/Proximity indices for the large gorgonian coral VME polygons in the NRA.

Distance Measurement Method	**Mean Nearest-Neighbour Distance Over All Polygons Pairs**	**Nearest Neighbour Ratio**	**Proximity Index (PX)**
Centroid-Centroid	320	1.249804	
Edge-Edge	299		255.1

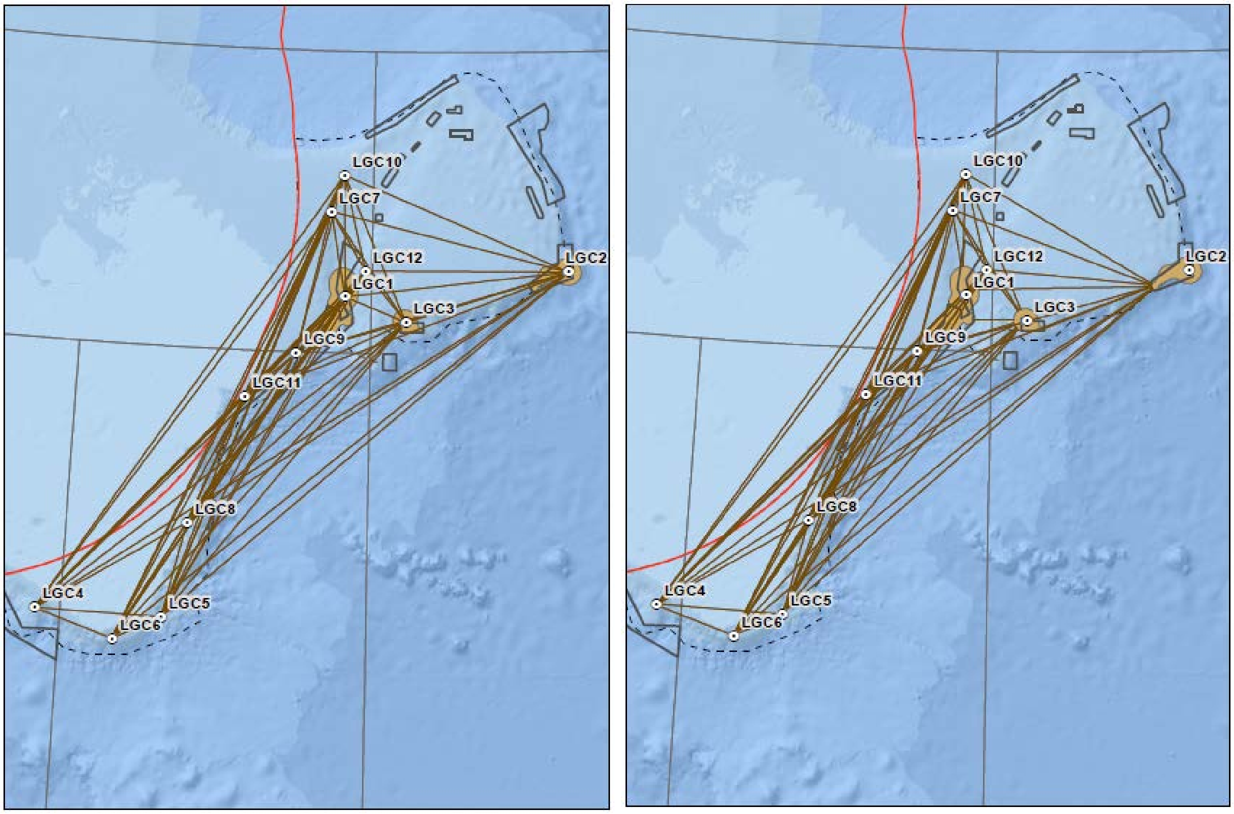


Figure 7.93. Nearest neighbour distance lines between large gorgonian coral VME polygons in the NRA calculated from centroid to centroid (Left panel) and from the nearest edge (Right panel). NAFO closed areas for the protection of corals and sponges are indicated in grey. Polygons are numbered according to decreasing area.

Application to the Closed Areas in the NAFO Regulatory Area

The results of the analyses applied to the NAFO closed areas (NAFO, 2021) are shown in Table 7.59 and Table 7.60. The distances between the closed areas (Figure 7.94) ranged from 29 to 842 km centroid to centroid, and 11 to 775 km edge to edge. Using the distances from centroid to centroid, shown in the lower diagonal of Table 7.59, the values for the mean nearest-neighbour distance over all polygons and the average nearest neighbour ratio are provided in Table 7.60. The values for the mean nearest-neighbour distance over all polygons and PX are provided for the edge-edge distances (Table 7.60).

Table 7.59. Nearest neighbour distances (km) calculated from centroid to centroid (below diagonal, shaded) and from nearest edges (above diagonal) for the closed areas in the NRA (numbered as in Figure 7.94). The mean nearest-neighbour distance for each closed area, as a measure of relative isolation, is shown below the rows for the centroid-to-centroid distances and to the right of columns for the nearest edges distances. Closed areas are numbered according to the NAFO Conservation and Enforcement Measures.

	Polygon Area (km^2)	3O	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9	Area 10	Area 11	Area 12	Area 13	Mean Nearest-Neighbour Distance (Edge-Edge)
3O	14184.4	---	215	284	497	697	775	669	748	765	738	649	615	704	542	608
Area 1	143.8	273	---	55	254	454	532	470	518	541	518	427	386	480	299	396
Area 2	5421.4	508	257	---	52	202	230	127	176	198	174	83	43	137	58	140
Area 3	307.6	548	280	85	---	178	254	259	268	295	276	199	159	244	27	228
Area 4	1357.6	775	506	287	228	---	48	229	162	195	207	205	191	204	133	239
Area 5	2878.6	842	588	335	316	169	---	80	42	57	81	127	183	107	205	209
Area 6	987.5	774	542	288	305	261	136	---	44	23	16	34	91	33	221	177
Area 7	258.0	791	546	289	287	199	71	68	---	20	20	58	123	36	225	188
Area 8	97.9	809	568	311	313	225	81	56	29	---	8.8	72	144	49	253	202
Area 9	127.7	782	544	287	296	234	107	29	39	31	---	48	121	25	234	190
Area 10	315.6	702	465	209	229	229	161	79	94	107	80	---	32	11	159	162
Area 11	60.5	650	408	152	174	222	199	137	141	160	135	58	---	84	121	176
Area 12	35.1	743	504	248	260	224	128	46	57	67	40	40	96	---	202	178
Area 13	338.4	593	328	104	49	186	267	262	239	266	251	188	137	216	---	206
Mean Nearest-Neighbour Distance (Centroid-Centroid)		676	447	258	259	288	262	230	219	233	220	203	205	205	237	

Table 7.60. Isolation/Proximity indices for the VME closures in the NRA.

Distance Measurement Method	Mean Nearest-Neighbour Distance Over All Polygons Pairs	Nearest Neighbour Ratio	Proximity Index (PX)
Centroid-Centroid	282		
Edge-Edge	236		452.0

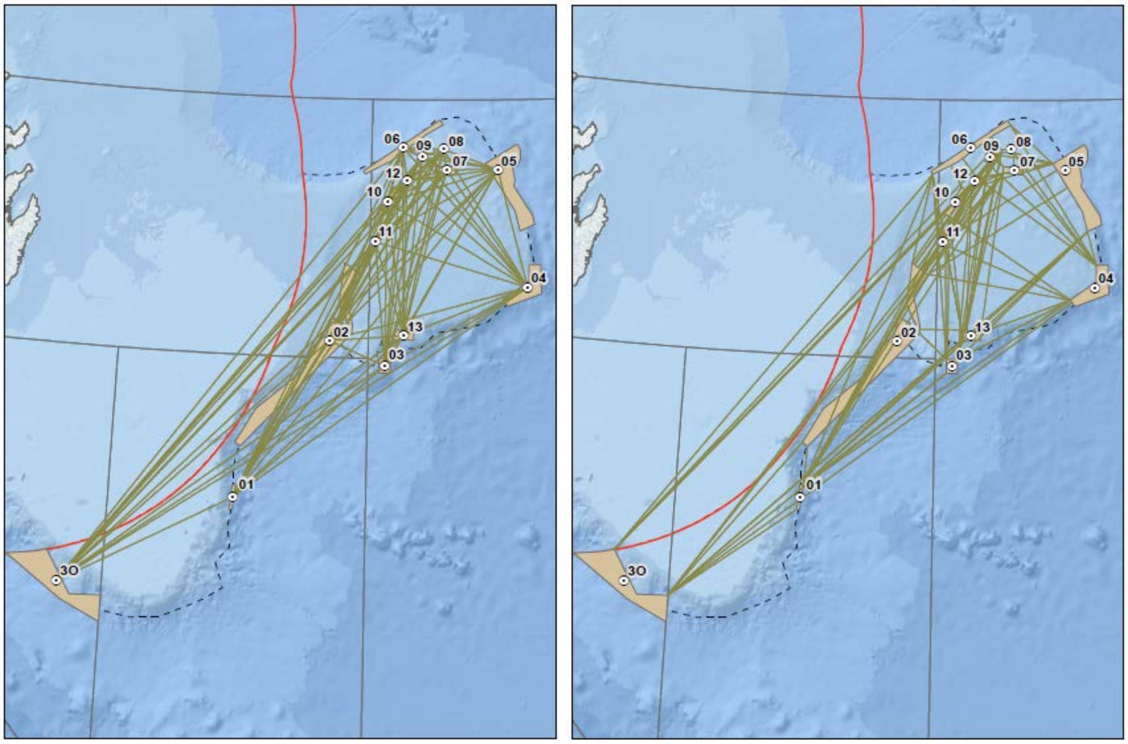


Figure 7.94. Nearest neighbour distance lines between areas closed to protect coral and sponge in the NRA calculated from centroid to centroid (Left panel) and from the nearest edge (Right panel). Areas are numbered as in the NAFO Conservation and Enforcement Measures (NAFO, 2021).

Evaluation of the adequacy of the spatial configuration of NAFO Closed Areas: Consistency Indicator

VMEs do not constitute isolated habitat patches, but rather are linked to one another creating an interdependence amongst them (network). While the reliance on self-recruitment versus immigration to maintain a given habitat patch is expected to be a function of the VME-specific biology and ecology, together with the local and neighbouring environmental conditions (see Section 7a)), the functional role of VMEs at the larger ecosystem level (see Section 7.b)iv) is dependent on maintaining the integrity of the habitat network defined by the individual VME units.

The VME networks observed today can be considered the remnants of their former selves, resulting from a history of anthropogenic, mostly fishing, impacts. It is unclear how these historical impacts may have affected ecological functionality, but one important component of maintaining their current ecological functionality is to preserve the integrity of the existing VME networks (see Section 7.b)iv).

A simple way to conceptualize a VME network is to consider, on one side, the area/biomass/structure of each VME as metrics of the network nodes, and the distribution of distances between VME units as a metric of the spatial distribution of the nodes in the network. It follows that preserving the integrity of the VME network would require both, an adequate protection of the nodes themselves (*i.e.*, adequacy of Closed Areas), as well as an adequate protection of the spatial structure defined by those nodes (*i.e.*, adequacy of the spatial configuration of the system of Close Areas).

The adequacy of the Closed Areas in terms of area, biomass and/or function is being considered in other sections of the SAI/VME and closed area assessments; here the focus is on evaluating the adequacy of the spatial configuration of NAFO Closed Areas with respect to the VMEs. This evaluation was based on the comparison of the edge-to-edge distances between the VME polygons for each of the 7 VME Indicators (Tables 7.46, 7.48, 7.50, 7.52, 7.54, 7.56, 7.58), and the Closed Areas (Table 7.60) established to protect those VMEs. The premise is simple, if the spatial configuration of Closed Areas is adequate, then the distribution of distances, and consequently the average distance between Closed Areas, should be similar to the ones observed for the corresponding VME. A large discrepancy between metrics from Closed Areas and VME would indicate a poor match between their spatial distributions, and hence, indicating a poor adequacy of the spatial configuration of the NAFO Closed Areas.

This evaluation was done by VME Indicator type and consisted of two elements. The first one was the comparison of the relative cumulative distribution of distances between VME polygons and Closed Areas. These distributions provide a visual assessment of the discrepancy between VME and Closed Areas spatial configurations. The second one was the statistical comparison of the average edge-to-edge distances between VME polygons and Closed Areas using t-tests. If the spatial distribution of Closed Areas is consistent with the spatial distribution of VME polygons it would be expected not just that these statistical comparisons would be non-significant, but that the *p*-values from these comparisons would reflect how close the two average distances are. Taking advantage that *p*-values range from 0 to 1, the *p*-values from these tests were considered as a **Consistency Indicator** between the Closed Areas and VME distributions, where values close to 1 would indicate very high consistency, and values closed to 0 (including statistically significant *p*-values of 0.05 or less) would indicate very poor consistency, but keeping in mind that this indicator should not be assumed linear (*i.e.*, a *p*-value of 0.5 can still indicate a very good consistency; this indicator needs to be interpreted in conjunction with the relative cumulative distribution). The results of these tests, paired with the cumulative distributions, provide a simple yet effective way of evaluating the adequacy of the spatial configuration of NAFO Closed Areas for providing protection to the current VME networks.

Out of the seven VME types currently identified in the NRA, only five are protected by Closed Areas (sea pens, large-size sponges, large gorgonian corals, small gorgonians and black corals). The existing Closed Areas were established for the protection of sea pen, sponge, and large gorgonian coral VMEs; the protection provided to small gorgonian and black coral is the result of co-occurrence of these VMEs within Closed Areas targeting other VME types. Sea squirts and bryozoans have no protection. These distinctions are important in the interpretation of results; the level of adequacy for VME types not originally targeted by Closed Areas has no bearing on the nature of the management process that created the Closed Areas, while results for sea pen, sponge, and large gorgonian corals are informative of the new information on those VME types, as well as the trade-offs between conservation and fishing made during the original delineation of Closed Areas.

Results indicate that the spatial configuration of NAFO Closed Areas was very good for sponge VME, showing very closed relative cumulative distributions between Closed Areas and VME units (Figure 7.95) as well as similar average edge-to-edge distances with a Consistency Indicator of 0.4 (Figure 7.96). However, results for the other two VME types originally considered in the establishment of Closed Areas were not as good.

In the case of sea pen VMEs, the relative cumulative distributions indicates than Closed Areas tend to be much closer than VME units (Figure 7.95), rendering a significantly shorter average edge-to-edge distance among Closed Areas in comparison with VME units (Figure 7.96). This is consistent with the lack of Closed Areas targeting sea pen VME units in the eastern side of the Flemish Cap and the Tail of the Grand Bank. Note Area 14 was not considered in this assessment as it was opened to fishing in 2019 and remains open.

The results for large gorgonian corals also showed a clear mismatch between the spatial distribution of Closed Areas and VME polygons (Figures 7.95, 7.96). In this case, this difference is mostly driven by the fact that Closed Areas have targeted large VME units only (see Figures 7.93. and 7.94), leaving small VME units without protection (see Table 7.59 for info on the area of VME polygons). As a consequence of this approach, the network of Closed Areas do not capture the spatial structure of the small VME polygons.

Among the VME Indicator types not originally considered for the establishment of Closed Areas, only small gorgonian corals and black coral VME polygons received protection. Unsurprisingly, the spatial configuration of the Closed Areas did not provide a good match for the VME distributions of those VME Indicators (Figures 7.95, 7.96), with Closed Areas been on average much closer than VME units in the case of black corals, and much further apart in the case of small gorgonian corals. It is also worth mentioning the similarities in the results from sea pen and black coral VMEs, both in terms of relative cumulative distributions and average edge-to-edge distances; the closeness of these results is not unexpected given the general co-occurrence/apparent association between sea pen and black coral VMEs (Figures 7.88 and 7.90), but highlights that a Closed Area spatial configuration that provides an adequate protection to sea pens is likely to also provide an effective coverage of the black coral VME network.

Overall, the spatial configuration of Closed Areas appears very good for sponges, but insufficient for other VME Indicator types, but with the added qualification that the spatial configuration of Closed Areas for large gorgonian corals appears adequate for large-sized VME units, but does not properly capture the distribution of the small-sized large gorgonian coral VME polygons.

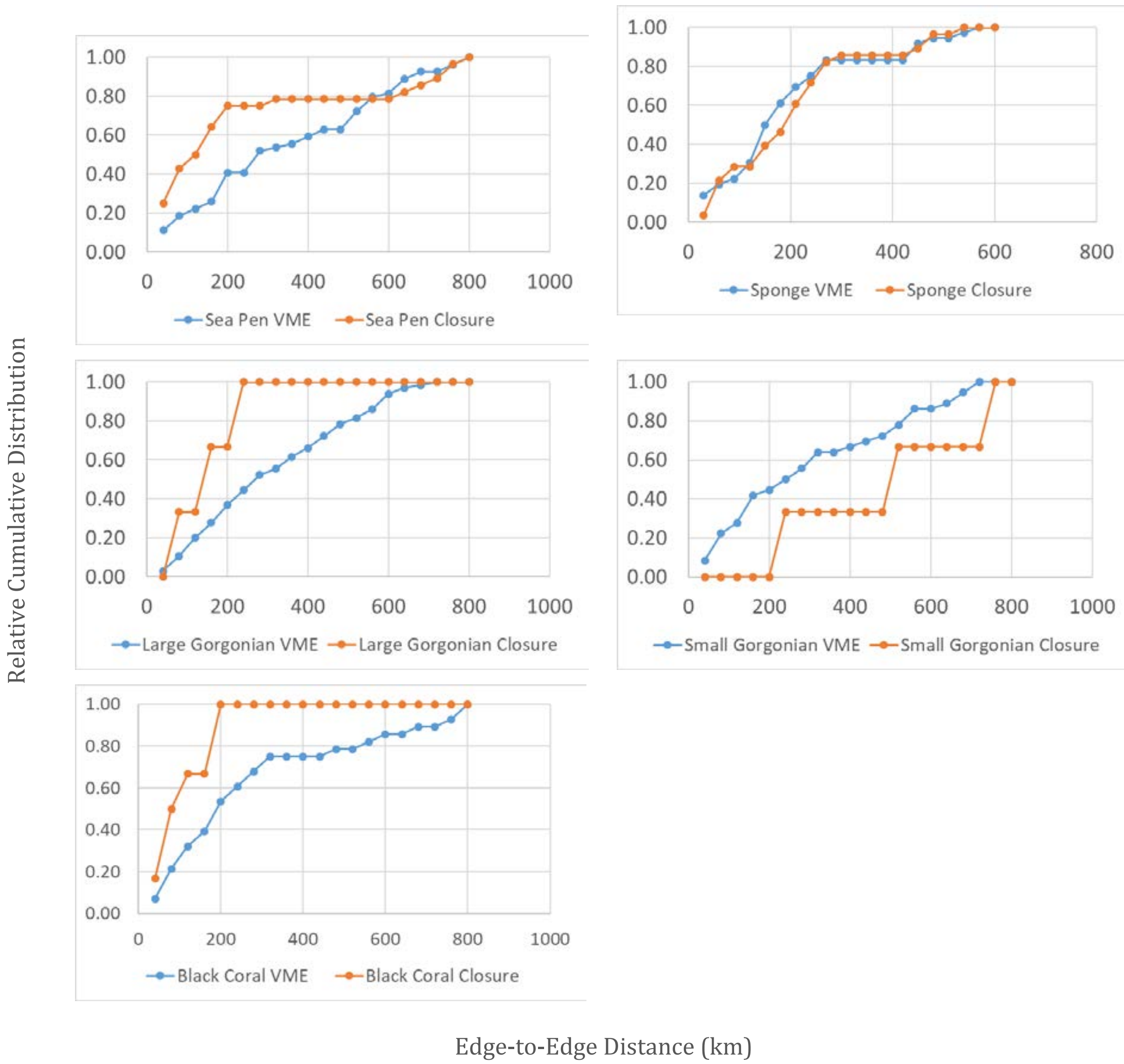


Figure 7.95. Relative cumulative distribution of the edge-to-edge distances for VME polygons and Closed Areas for sea pens, large-sized sponges, large gorgonian corals, small gorgonian corals and black coral VMEs. The remaining VME types are not currently protected by closures.

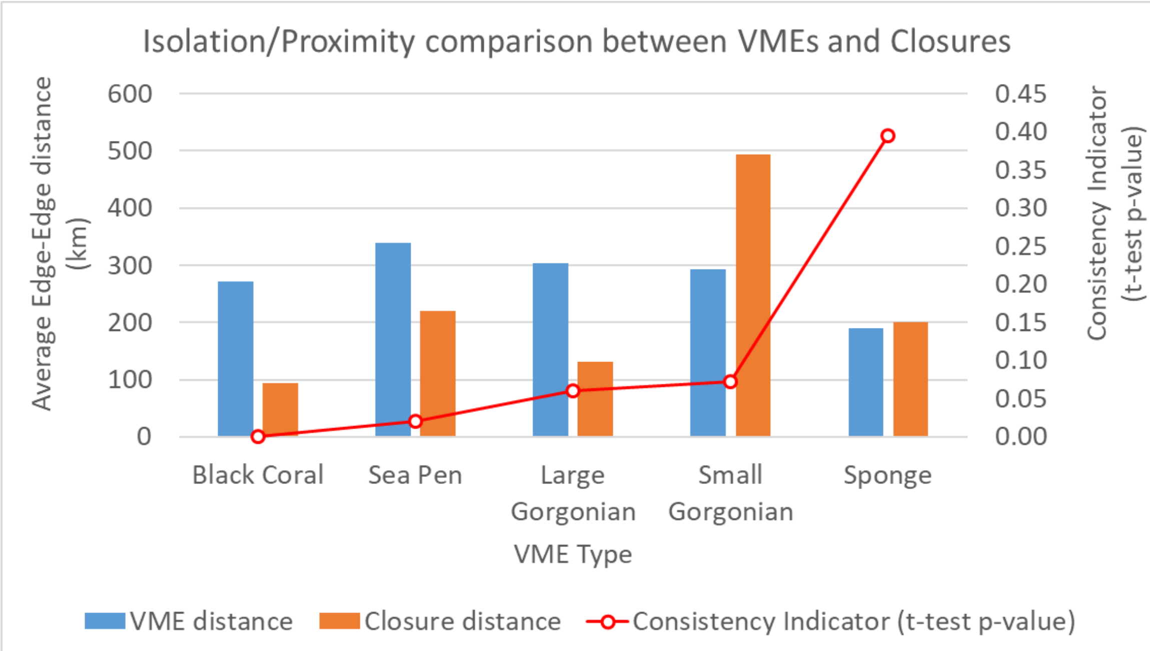


Figure 7.96. Comparison of the average edge-to-edge distance between VME units and Closed Areas, and corresponding Consistency Indicator (p-value of the t-test for differences between the means) for sea pen, large-sized sponges, large gorgonian corals, small gorgonian corals, and black coral VMEs.

Future Work

The distance matrices used in our assessment include connections between VME polygons and between Closed Areas that may not occur, or may occur with differing degrees of connectivity (see Section 7)vi). Removal of connections that are unlikely to occur due to the prevailing oceanographic currents, and recalculation of the indices is proposed for the next phase of development of this index. This has been done for the Closed Areas (Wang *et al.*, 2020), but not for the VME polygons.

Further, we propose to undertake simulation modeling to explore the impacts of fishing on the indices, and hence to evaluate the ability of the indices to respond to significant adverse impacts of fishing. Simulation modeling is the process of creating and analyzing a digital prototype to predict outcomes. Simulation models should improve both our ecological knowledge of the observed network phenomena as well as the applications of landscape ecology to conservation and management (DeAngelis and Yurek, 2017). Manipulations of the data will be undertaken to determine the effect of altering the isolation of patches within the same spatial extent on PX following Gustafson and Parker (1994). Simulation work imitating fishing using actual VMS data and manipulated trawling activity will be used to create test scenarios to evaluate sensitivity of the indices to fishing activity following Costanza and Voinov (2004). This type of work is expected to also be integrated/explored within the sea pen ABM being developed.

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xi) Overall assessment of SAI

Selected SAI metrics

To conduct an overall assessment of SAI, the full set of assessment metrics (as detailed above) were compiled into a single table for evaluation purposes. Ideally, we would wish to take the output of FAO criterion **ii**, "the spatial extent of the impact relative to the availability of the habitat type affected", and through consideration of FAO criteria **iii** through **vi**, state whether the calculated impact on VME is significant or not.

However, despite the recent advances made since the 1st assessment in assessing the functional attributes of VMEs, the quantification of the VME functions in the protected, at risk and impacted assessment categories cannot be performed at the present time, as explained in Section 7.b)vii. Research therefore continues to address the functional significance of VMEs and to resolve some of the challenges identified associated with integrating different functional biomass datasets into one standardized biomass layer. Nevertheless, there are several other attributes of VMEs (including functional attributes) which can be assessed for which reliable and robust data are available. For example, **i.** the proportion of area or biomass of VME which is assessed to be protected, compared to that which is at high risk of impact or impacted, **ii.** the number and area of overlapping VMEs, **iii.** the relative sensitivity of VMEs, **iv**. fishing area stability, **v.** the level of VME fragmentation or proximity, **vi.** the level of VME closure connectivity and, vii. The number of overlapping VME functions. Each of these assessment metrics, which are defined in Table 7.61, can be quantitatively evaluated, and collectively assessed using expert judgement to determine the overall likelihood or risk of SAI occurring.

During the 1st SAI assessment, a set of assessment metrics were defined, these have been re-evaluated and additional metrics included to assess the functional characteristics of VME and the impacts of bottom fishing activities. The full set of assessment metrics, including their definitions, as used in the present (2nd) assessment are shown in Table 7.61.

Table 7.61. The full set of assessment metrics applied in the 2nd reassessment of bottom fisheries SAI.

SAI Assessment Metrics	Definition
Area/Biomass protected (low risk)	This refers to the proportion of the area or biomass of VME which is currently at low risk either because it falls within a fishery closure area and/or is in an area outside of the fishing footprint. (see Section 7.d)iii).
Area/Biomass impacted	Proportion of the area or biomass of VME which has been exposed to a level of fishing effort above the defined cut-off point within any one year. (See Section 7.d)iii).
Area/Biomass at high risk	Proportion of the area or biomass of VME which falls below the defined cut-off point of fishing effort within any one year not protected. (See Section 7.d)iii).
Proportion of overlapping VME in closures	Proportion of VME area and biomass overlapping with 2 or more VME types inside VME closures. The greater the proportion of overlapping VME area/biomass protected by closures the lower the risk of SAI occurring (See Section 7.d)x).
Index of VME sensitivity	The inverse of VME impact cut-off value is used as a proxy of sensitivity as it indicates the point at which trawl duration/length exceeds VME indicator patch size within the habitat. The higher the sensitivity the greater the risk of SAI occurring (See Section 7.d)v).
Index of fishing stability	The proportion of the total fishing effort for each VME associated with cells repeatably fished above the impact cut-off value over a 10 period. The greater the proportion of effort associated with areas fished repeatably above the cut-off value in 10 out of 10 years, the more spatially stable the fishery is, and therefore the lower risk of new SAI occurring (See Section 7.d)x)
Index of VME fragmentation/proximity	The spatial extent (size) and location (distance) of VME polygons in relation to its neighbours of the same VME type. The more fragmentation (a low index value) the greater the risk for SAI. (See section 7.d)x).
Number of overlapping functions in unprotected VME areas	The number of functional types with an overlap of >50% in each VME type not protected by closures or the fishing footprint. The more overlapping functional types unprotected the greater the risk of SAI occurring at the functional level (See Section 7.d)ix).

The results of applying these assessment metrics in the NRA are summarized in Table 7.62 and Table 7.63, as absolute values and percentages, respectively.

Table 7.62. The absolute VME Area (km²) and Biomass (kg) for each VME type in each of the protected (low risk), high risk and impacted assessment categories. For all other SAI assessment metrics and their definitions (including their units of measurement) refer to table 7.61.

	Sponge		Sea pen		Large gorgonian		Small gorgonian		Black Coral		Bryozoan		Sea Squirt	
SAI metric	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**
VME Protected (low risk)	16,572	257,025,819	1,609	35,964	3,234	116,965	84	61	521	2,615	5	4	17	215
VME At Risk	5,056	18,391,708	6,666	62,344	1,341	14,810	3,489	2,902	1,744	6,905	3,343	65,210	3,247	36,174
VME Impacted	4,383	1,567,898	810	1,936	840	1,673	1,183	388	534	922	150	353	817	5,183
VME Fragmentation/Proximity	1,112		394		255		125		109		717		802	
Fishing Stability (over 10 yrs.)	274,479		49,198		38,864		277,194		12,230		0		34,053	
VME Sensitivity	3.3		0.2		1.7		0.5		1.4		0.1		0.5	
Overlapping VMEs in Closures (km² and kg)	2,669	38,052,610	645	17,296	2,581	89,801	80	40	435	2,133	5	5	0	0
Overlapping Functions in unprotected VME areas (count)	2		4		2		1		3		4		4	

Table 7.63. The proportion of the VME Area (km²) and Biomass (kg) for each VME type in each of the low risk, high risk and impacted assessment categories. For all other SAI assessment metrics and their definitions refer to table 7.61.

	Sponge		Sea pen		Large gorgonian		Small gorgonian		Black Coral		Bryozoan		Sea Squirt	
SAI metric	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**
VME Protected (low risk)	64%	93%	18%	36%	60%	88%	2%	2%	19%	25%	0%	0%	0%	1%
VME At Risk	19%	7%	73%	62%	25%	11%	73%	87%	62%	66%	96%	99%	80%	87%
VME Impacted	17%	1%	9%	2%	16%	1%	25%	12%	19%	9%	4%	1%	20%	12%
Overlapping VMEs in closures (km² and kg)	62%	99%	19%	42%	65%	82%	9%	9%	21%	23%	4%	3%	0%	0%
Fishing Stability (over 10 yrs.)	82%		39%		44%		80%		54%		0%		39%	

Weighting of the SAI assessment metrics

It was noted by SC that one of the principal limitations of the assessment is that all metrics applied to each VME have equal weight, when it is likely that some of metrics will have a greater significance for the assessment of SAI than others. In addition, the rationale for assigning the categories of 'high, moderate and low' to VME specific metric values was not clear.

To address these concerns a sub-group of WG-ESA was convened to first consider the full list of SAI criteria (FAO, 2009) with respect to the expanded list of assessment metrics to be applied to the reassessment of bottom fisheries in 2021 (the 2nd SAI assessment) (Table 7.64). It was noted that the first two SAI criteria are essentially directly related to the management of the fishing activity and therefore their status and trend will largely drive the responses in the remaining 4 criteria (see footnote 64).

Table 7.64. Full list of SAI criteria (FAO, 2009) with respect to an expanded list of assessment metrics to be applied to the reassessment of bottom fisheries in 2021

	SAI criteria FAO[64]					
SAI Assessment Metrics	**i**	**ii**	**iii**	**iv**	**v**	**vi**
Area/Biomass Protected	x	x		x		
Area/Biomass impacted	x	x				x
Area/Biomass at high risk	x	x				
Proportion of overlapping VMEs			x		x	
Index of VME sensitivity			x	x		
Index of fishing stability	x	x				
Index of Risk of VME fragmentation/proximity	x	x				
Overlapping Functions in unprotected VME areas			x	x	x	

Accordingly, the metrics which correspond to the assessment of the first two SAI criteria were considered to be of greater importance (and hence influence) in determining the overall assessment of SAI. Nevertheless, the full list of metrics for the 2nd SAI assessment were applied to meet the requirements of all 6 SAI criteria, including those pertaining to VME functions (~~see~~ Table 7.61 footnote 64).

Overall SAI scores by VME type

In the 1st assessment of SAI, three categories (or scores) of assessment were applied to each metric value, namely, 'high, moderate and low'. The limits used to define the scores were selected to highlight the relative differences between the VME specific metrics. Although in most cases the differences were sufficiently clear to assign either a high or low assessment score to each metric, the actual significance of the values in relation to ecosystem function and impact was not known. For the present and future assessments, it was considered important to agree and define a set of objective criteria for the SAI assessment scores, especially as applied to

[64] **i.** the intensity or severity of the impact at the specific site being affected; ii. the spatial extent of the impact relative to the availability of the habitat type affected, iii. the sensitivity/vulnerability of the ecosystem to the impact; iv. the ability of an ecosystem to recover from harm, and the rate of such recovery, v. the extent to which ecosystem functions may be altered by the impact; and **vi**. the timing and duration of the impact relative to the period in which a species needs the habitat during one or more of its life history stages.

the first assessment metric (*e.g.,* area/biomass protected). Also, to ensure consistency between the assessment score categories used in the review of VMEs in 2019 (NAFO SCS Doc. 19/25) and the present assessment of SAI, the same general VME 'protected' score categories (breakpoints) were applied (Table 7.65). It was concluded by WG-ESA that the assignation of SAI scores (low, intermediate, high) to the 'at risk' and 'impacted' SAI metrics was not appropriate for the present assessment[65], and that the overall weighting of the SAI assessment should be based primarily on the 'protected' SAI metric score, with the scores assigned to all other SAI metrics simply providing some overall context and confidence in the assessment of the 'protected' SAI risk score.

Furthermore, it was noted that the VME 'protected', 'at risk' and 'impacted' metrics are not mutually exclusive of one another, *e.g.*, an increase in the biomass protected will (by definition) result in a decrease in the combined biomass 'at risk' and 'impacted' categories and therefore the potential risk of SAI would decrease accordingly. Therefore, by focussing the result of the assessment on the protected VME biomass status, the assessment is essentially one which determines the ***risk of SAI occurring*** as opposed to the assessment of whether or not ***SAI has occurred***.

Further discussion and research will be undertaken by WG-ESA to establish what proportion of the 'at risk' category is likely to be subject to sustained fishing activity to enable an appropriate assessment of bottom fishing impacts to be undertaken. However, the question of quantifying what loss of VME biomass constitutes a ***significant*** impact, will depend on further developments in quantifying the VME functions as discussed in Section 7.d)vii.

The score criteria applied for all assessment metrics used in the overall assessment of SAI is shown in Table 7.66.

[65] It was noted that VME defined 'at risk' of impact (that is VME outside areas protected and where the fishing effort is less than the cut-off value) is not devoid of any fishing activity. It would therefore be expected that a proportion of the fishing effort in the 'at risk' area would be associated with a quantifiable and sustained level of impact. However, it has not been possible to quantify the level of impact that this fishing activity represents. For example, simply identifying all areas of fishing below the cut-off value within the area 'at risk' would most likely overestimate the 'true' (or sustained) area of impact, since it is known that at very low levels of fishing effort the probability of the same area of seabed being fished twice or more within the life expectancy of some of the least sensitive VME taxa will be very low, therefore recovery of the biomass in those areas impacted by the first pass of a trawl would be expected to occur before being impacted again. Nevertheless, there is also likely to be a significant underestimate of the true area of impact by simply using the cut-off value at 95% of the cumulative biomass, since we know that fishing at levels close to the fishing impact cut-off value will have an intensity and frequency of impact that the likelihood of any biomass recovery will be very low in these areas.

Table 7.65. Definition of categories used to assess the protection status of VMEs. Status definitions (recommendations) are based on definitions from the online Oxford English Dictionary: Good – To be desired or approved of; Adequate – Satisfactory or acceptable in quantity or quality; Incomplete – Not having the necessary or appropriate parts; Limited – Restricted in size, amount, or extent; Poor – Of low or inferior standard or quality; Inadequate – Lacking in quality or quantity required.

SAI Score[66] Categories	VME Status	Proportion of biomass protected	Projected Connectivity Among Closures	Management Action
Good (Low SAI risk) >60%	Good	> 60% VME Biomass	Good connectivity	Beneficial
	Adequate	> 60% VME Biomass	Limited connectivity or redundancy	Beneficial
Limited (Intermediate SAI risk) 30% - 60%	Incomplete	60% - 30% VME Biomass	Good connectivity	Desirable
	Limited	60% - 30% VME Biomass	Limited connectivity or redundancy	Desirable
Poor (High SAI risk) <30%	Poor	30% - 15% VME Biomass	Limited connectivity or redundancy	Essential
	Inadequate	< 15% of Biomass	Limited connectivity or redundancy	Essential

Table 7.66. Overall SAI score category criteria as applied to each of the SAI assessment metrics. The first SAI metric uses the same categories as applied during the 2nd review of VMEs. For each of the remaining SAI metrics the breakpoints were generally set by dividing the range in values by 3 and rounding to the nearest whole number.

SAI metric	SAI Score Categories		
	Good (Low SAI risk)	Limited (Intermediate SAI risk)	Poor (High SAI risk)
VME Protected	> 60%	30% - 60%	< 30%
VME At Risk	-	-	-
VME Impacted	-	-	-
VME Fragmentation/Proximity	>740	340 - 740	< 340
Fishing effort stability Index (over 10 yrs.)	> 60%	30% - 60%	< 30%
VME Sensitivity Index	< 0.5	0.5 - 1	>1
Proportion of VME area/biomass overlapping in closures	> 60%	30% - 60%	< 30%
Number of overlapping functions (>50%) in unprotected VME	<2	2 - 3	>3

An expert comparative evaluation of the results presented in Tables 7.62 and 7.63 was undertaken such that each result was assigned a relative SAI score (*e.g.*, low, intermediate, and high risk), according to the criteria specified in Table 7.66. For example, if a VME has a large proportion of its area and/or biomass protected (>60%) then it would be assigned a 'good' rating. By contrast, if a VME has a relatively high level of sensitivity (*e.g.,* a low inverse fishing effort/cumulative biomass cut-off value, >1) then it would be assessed as being potentially more at risk of SAI and would receive a 'poor' rating. Except for the VME 'protected' metric, the score category breaks were defined by dividing the range of the metric values by 3 and rounding to the nearest whole number where appropriate. The overall results of the expert assessment of all SAI metrics against the SAI score categories is given in Table 7.67.

66 For the review of VMEs (NAFO SCS Doc. 19/25) 6 assessment categories were used. In the present assessment these have been grouped into 3 assessment categories as shown.

Table 7.67. Overall SAI assessment scores for each VME and SAI metric categorised as either good (low risk), limited (intermediate risk), or poor (high risk), following the SAI score categories as defined in Table 7.66, with the overall SAI Risk based upon the count of 'poor' and 'good' ratings for each VME using biomass data where appropriate.

	Sponge		**Sea pen**		**Large gorgonian**		**Small gorgonian**		**Black Coral**		**Bryozoan**		**Sea Squirt**	
SAI metric	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**	**Area**	**Biomass**
VME Protected	64%	93%	16%	33%	60%	89%	2%	2%	17%	23%	<1%	<1%	<1%	1%
VME At Risk	19%	6%	74%	65%	23%	10%	72%	86%	63%	67%	96%	99%	79%	85%
VME Impacted	18%	1%	9%	2%	16%	1%	26%	12%	20%	10%	4%	1%	21%	14%
SAI Risk (biomass)	**Low**		**Moderate**		**Low**		**High**		**High**		**High**		**High**	
VME Fragmentation/Proximity	1,112		394		255		125		109		717		802	
Fishing effort stability (over 10 yrs.)	82%		39%		44%		80%		54%		0%		39%	
VME Sensitivity	3.3		0.2		1.7		0.5		1.4		0.1		0.5	
Proportion of VME area/biomass overlapping in closures (km^2 and kg)	62%	99%	19%	42%	65%	82%	9%	9%	21%	23%	4%	3%	0%	0%
Number of overlapping functions (>50%) in unprotected VME	2		4		2		1		3		4		4	
Overall SAI Risk[67]	**Low (1, 6)**		**Moderate (3, 1)**		**Low (2, 4)**		**High (5, 2)**		**High (6, 0)**		**High (6, 1)**		**High (5, 1)**	
Ranking for Management Action	**7**		**5**		**6**		**4**		**1**		**2**		**3**	

67 The overall SAI Risk score was calculated by simply counting the number of high-risk category scores (in red) and the low-risk category scores (in green) for both the area and biomass metrics. These numbers are shown in parenthesis, respectively. A combination of the high and low SAI risk scores provides the basis for ranking the management priority from high to low.

VME Management options

i) Introduction

In Request #6, the Commission asks that Scientific Council (SC), *in preparation of the re-assessment of NAFO bottom fisheries in 2021 and discussion on VME fishery closures*, (*Item iv) specifies that SC provide input and analysis of potential management options, with the goal of supporting meaningful and effective discussions between scientists and managers at the 2021 WG-EAFFM meeting*.

The WG reviewed the potential use of buffer zones around existing closures (Section 7.b)v) and the previous application of move-on rules (NAFO 2021) and concluded that for the latter, their value was limited because the greatest impact to VMEs often occurs during the first encounter and recovery will requires years to decades. Buffer zones could be useful in areas where indirect impacts of fishing, through sediment resuspension, could occur. However more work would be needed to model transport of suspended particles before the value of buffers could be evaluated and their incorporation considered as a management measure. Furthermore, review of existing closures revealed that increased protection was essential for five of seven VMEs in the NRA (Small Gorgonian Coral, Sea squirts (*Boltenia ovifera*), Erect bryozoans, Black Coral and Sea Pens) and desirable for two (Large-sized Sponges and Large Gorgonian Coral) (NAFO 2020). As a result, expert groups with diverse subject matter expertise evaluated the benefits and consequences of extensions to existing closures as well as the addition of areas in instances where no protection existed (NAFO 2020).

In evaluating possible management options for the protection of VMEs in the NRA, the subject matter experts gave careful consideration to the review of existing closures and the outcome of the SAI (Section 7.d) in evaluating possible tradeoffs required to achieve appropriate conservation measures and the possible consequences to ongoing bottom-contact fisheries. There are no established rules to quantify such tradeoffs, but the basic principles applied in expert deliberations were to reduce the risk of SAI and improve the protection of VMEs while limiting potential losses to harvesters relative to the overall activities for all fisheries monitored in the NRA.

ii) Contributing elements

Biomass and area estimates of Large-sized Sponges, Sea Pens, Sea Squirts (hereafter *Boltenia*), Erect Bryozoans, Black Corals, Large Gorgonian Corals, and Small Gorgonian Corals (Section 7.b)iii; Figure 7.2) generated from the output kernel density raster surfaces, with an increased resolution of 1 km^2, served as the foundation in the development of management options. An estimate of fishing stability with VME catches above the effort cut-off threshold (NAFO 2020) for each VME taxa (years fished km^{-2}) (Section 7.d)x) was overlaid with each VME polygon and closures along with VME catches above the biomass threshold to identify areas of high concentrations that could be considered at lower risk because of limited fishing activity. Boundaries were chosen to ensure the incorporation of known observations of high VME biomass to avoid potential impact by exposure to fishing activity.

Potential changes to existing closures were evaluated relative to the distribution of overall fishing effort ($km \cdot km^{-2} \cdot year^{-1}$) (Section 7.d)iv; Figure 7.40, Distribution of effort from trawl fisheries in the NRA between 2010 – 2019). The consequences to fisheries of any potential changes to existing closures were estimated based on the average haul-by-haul total and fishery specific catch biomass per distance of trawling ($kg \cdot km^{-1}$) provided by the Secretariat (2016-2019) and cumulative fishing effort (fishing effort × years fished [2010-2019]) averaged over the number of years each fishery (Cod, Redfish, Greenland halibut, Skate, and Total across all species) was active.

iii) Management options

Expert assessment of potential management options based on the outcome of the re-assessment of VME closures (NAFO 2020) and evaluation of risk of significant adverse impact (Section 7.d)vi). This yielded proposals for ten extensions to existing closures, the creation of three new closures, and modifications to Area 14 (Figure 7.97). The consequences to the protection of VMEs and the potential impact on fishing activities and catches are discussed fully in Section 7.e)iv. Detailed coordinates for each proposed closure or extension appear in Section 7.d)viii.

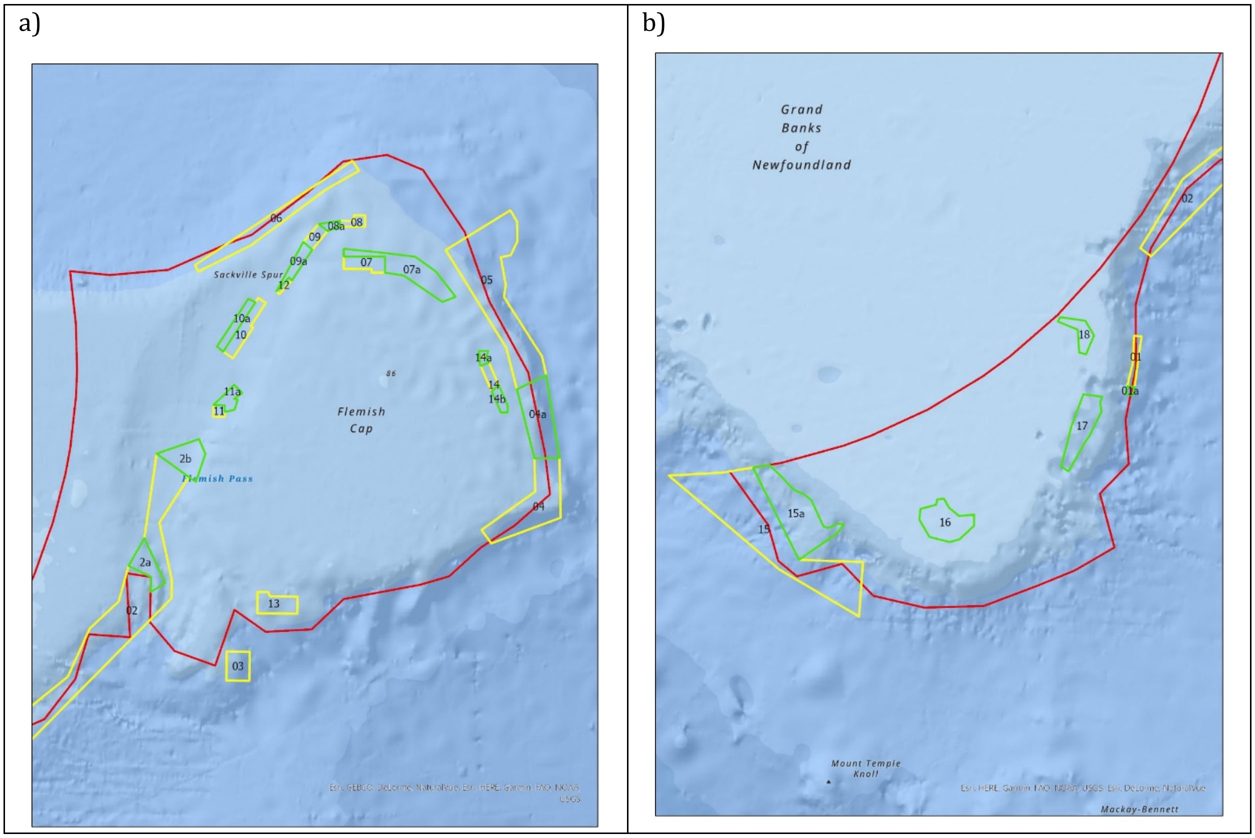


Figure 7.97. Location of existing closures (in yellow), proposed extensions, modifications and new closures (in green) in a) the northern, and b) southern portions of the NAFO Regulatory Area. The fishing footprint is indicated in red. Numerals represent existing or proposed new closures; number-letter combinations represent extensions or modifications to existing closures.

Division 3O Coral Closure and Area 1 Tail of the Bank

Area 1 – Tail of the Grand Bank Large-sized Sponge Closure

The Tail of the Grand Bank has important concentrations of Large-sized Sponges, Sea Squirts, Erect Bryozoans, Sea Pens, and Small and Large Gorgonian Corals (Figure 7.98.a). There is strong stability in fishing activity to the west of the Area 1 Large-sized Sponge closure but there is limited fishing activity on the southern of the closure where Large-sized sponge concentrations above the biomass threshold have been found (Figure 7.98.b). The expert assessment concludes that additional protection for Large-sized Sponges can be achieved and **proposes an extension of the Area Closure 1 (Area 1a)** (Figures 7.97, 7.98.a).

Boltenia are broadly distributed along the eastern edge of the Tail of the Grand Bank (Figure 5.3.2.a). Fishing stability is generally low over most of the *Boltenia* polygon (Figure 5.3.2.c). Notable occurrences of catches above the biomass threshold in areas with limited fishing activity in the northern-most polygon located east of the Southeast Shoal and in the northern portion of the VME polygon along the eastern portion of the Tail of the Grand Bank (Figure 7.98.c). There is currently very limited protection for *Boltenia* (<1% area; 1% biomass) but expert assessment **proposes the establishment of two new closures (Areas 17 & 18)** (Figures 7.97, 7.98.a) that would protect 21% of the areal distribution and 60% of the biomass of this VME (Tables 7.68, 7.69). The northern most proposed closure (Area 18) would also provide protection for overlapping bryozoans.

Bryozoans are also broadly distributed over the Tail of the Grand Bank but mostly in areas shallower than *Boltenia* (Figure 7.98.a). Two large areas with a high occurrence of catches above the biomass threshold were found west of the large *Boltenia* polygon, with the largest one to the southwest. Fishing stability over the northern most of these two areas is moderate to high (Figure 7.98.d) and does not represent a suitable area for closure because of the potential consequences to fishing activities. However, fishing stability above the effort cut-off threshold is very limited over the large southwestern polygon, with a high occurrence of catches above the biomass threshold in the center of that area where expert assessment **counsels for the establishment of a new closure (Area 16)** (Figures 7.97, 7.98.a). Less than 1% of the area and biomass of bryozoans is currently protected but the addition of the proposed closure would protect 20% of the areal distribution and 78% of the biomass of this VME (Tables 7.68, 7.69).

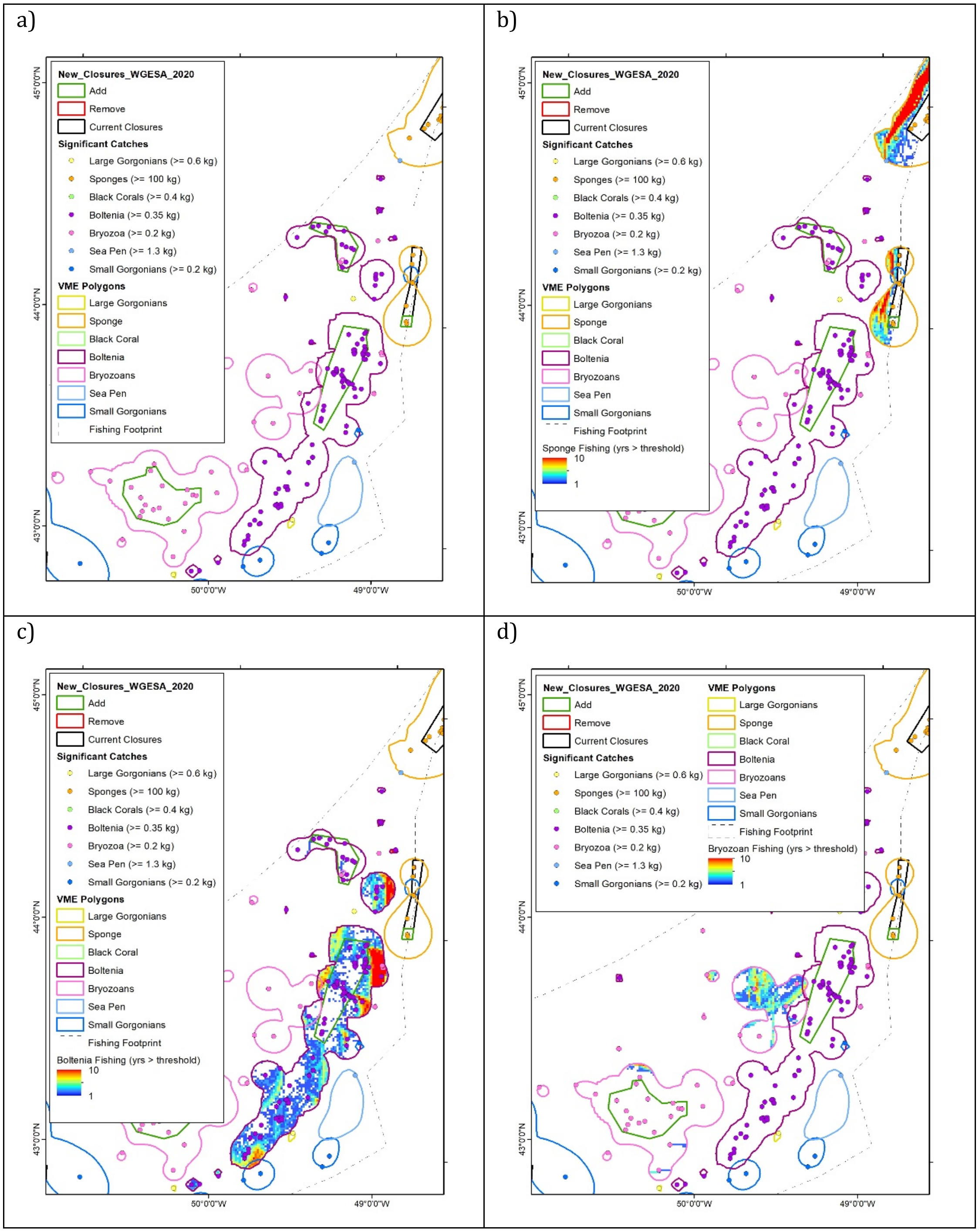


Figure 7.98. a) VME polygons and location of catches per RV tow above the biomass threshold values for VME taxa in proximity to the Area 1 Large-sized Sponge closure, showing existing closures (in black) and proposed extensions (in green); b) overlay of fishing stability (years above effort cut-off threshold) with the Large-sized Sponges polygons; c) overlay of fishing stability with the Boltenia polygons; and d) overlay of fishing stability for Erect bryozoans polygons.

Southwestern Tail of Grand Bank

NAFO (2020) identified important concentrations of Small Gorgonian Coral, Sea Pens and Large Gorgonian Coral on the southwestern edge of the Tail of the Grand Bank, in close proximity of the 3O Coral Closure (Figure 7.99.a). Evaluation of fishing activities relative to the distribution of Small Gorgonian Coral (Figure 7.99.b) and Sea Pens (Figure 7.99.c) revealed similar bathymetrically constrained areas of high fishing stability below which catches above the biomass threshold of Small Gorgonian Coral, Sea Pens and Large Gorgonian Coral occur. As a result of limited protection for Small Gorgonian Coral with existing closures and limited overlap with ongoing fisheries (2010-2019), the expert assessment **counsels for the creation of a new closure (Area 15a) to the east of the 3O closure in the NRA to protect important concentrations of Small Gorgonian Coral, Sea Pens and Large Gorgonian Coral** (Figures 7.97, 7.99.a).

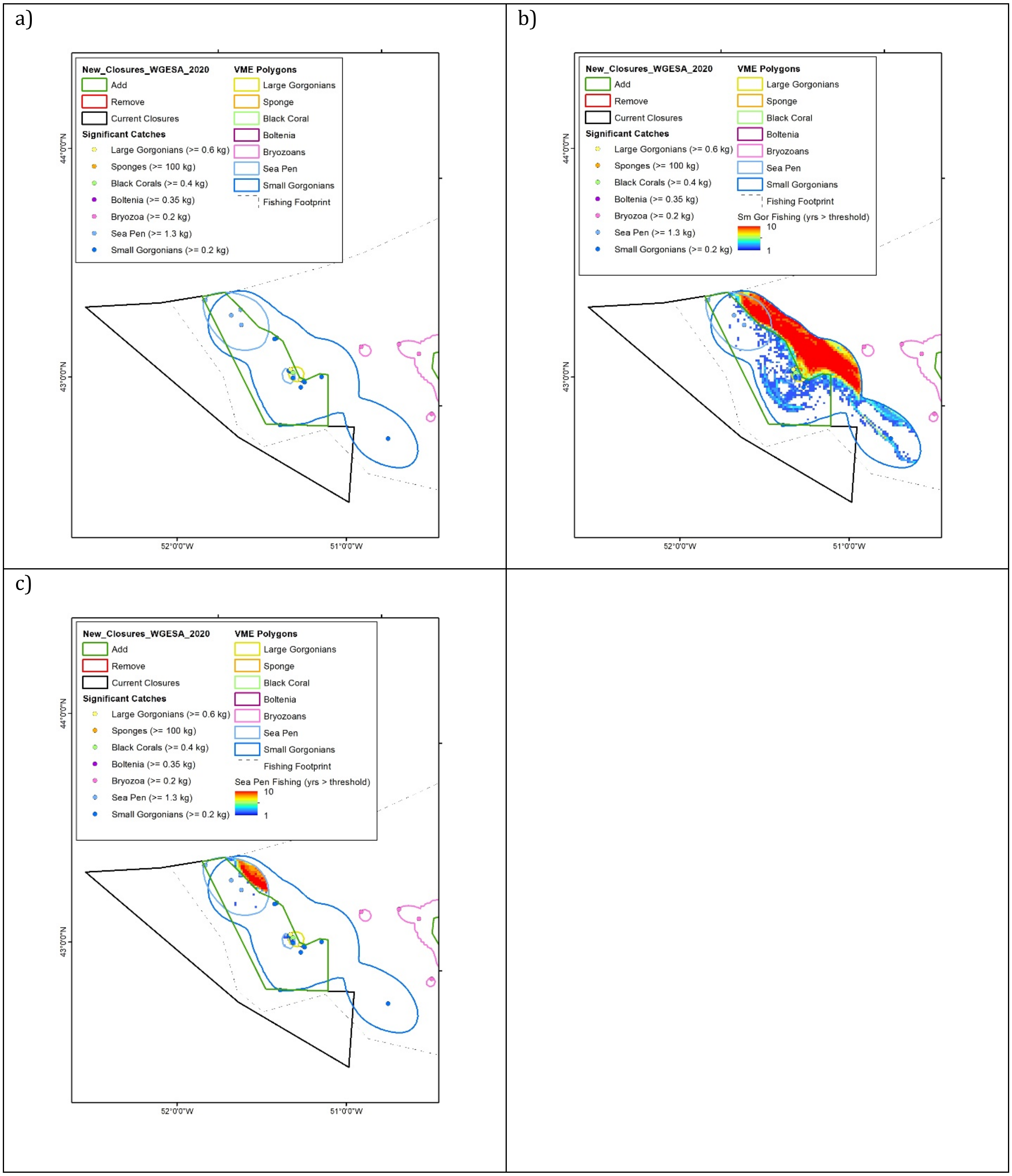
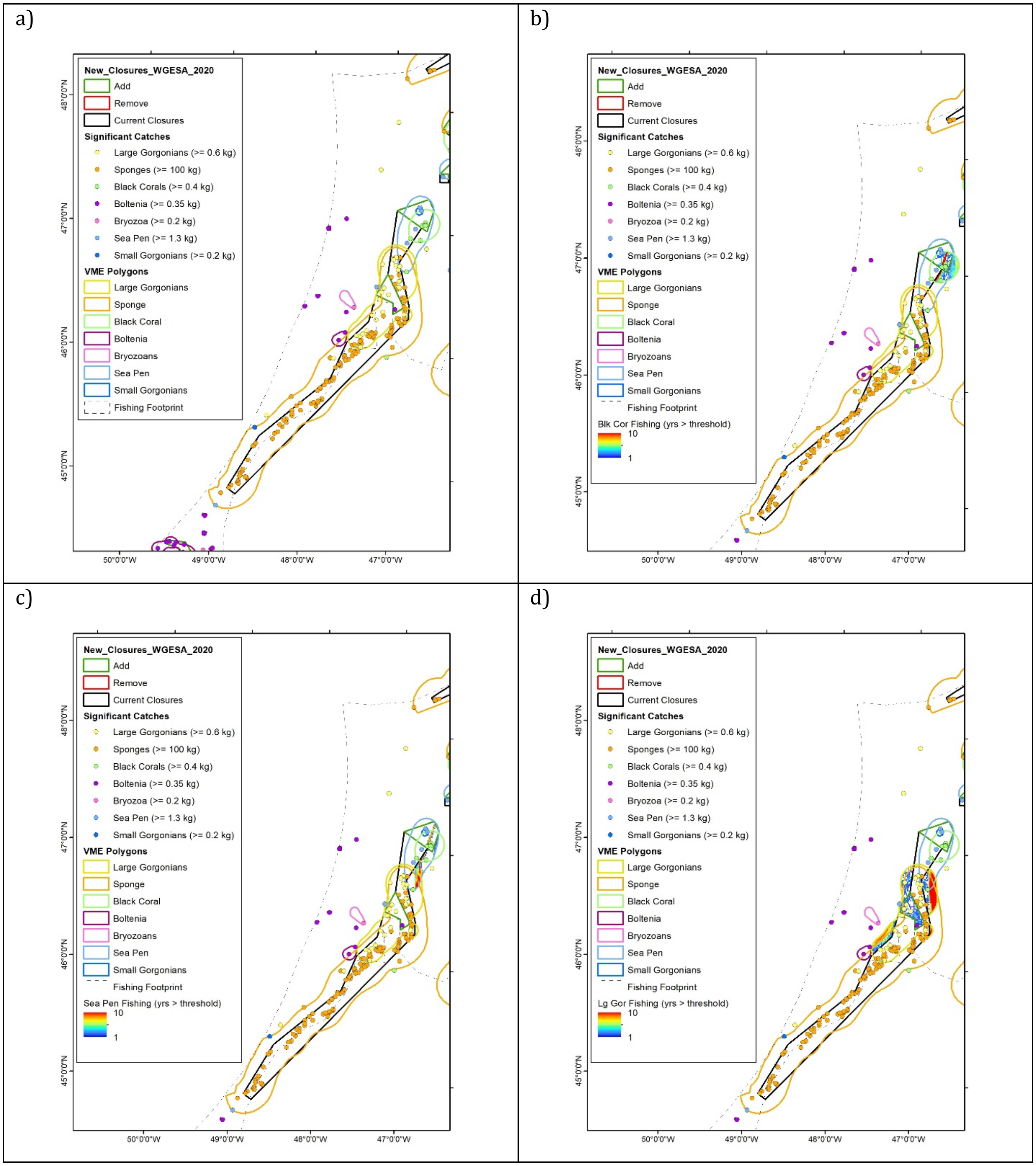


Figure 7.99. a) VME polygons and location of catches per RV tow above the biomass threshold values for VME taxa in the southwestern part of the Tail of the Grand Bank, showing the existing closure (in black) and proposed extensions (in green); b) overlay of fishing stability (years above the effort cut-off threshold) with the Small Gorgonian polygon; and c) overlay of fishing stability with the Sea Pen polygon.

Area 2 Flemish Pass/Eastern Canyon and Areas 3, 13 Beothuk Knoll

Area 2 Large-sized Sponge Closure

Large aggregations of Large-sized Sponge, Large Gorgonian Coral, Sea Pens and Black Coral occur in the vicinity of the Area 2 Large-sized Sponge closure. There is considerable overlap of Large-sized Sponge and Large Gorgonian Coral while Sea Pens and Black Coral co-occur in the northern part of Area 2 closure. Most occurrences of concentrations above the biomass threshold of these VMEs are found within the closure. However, the improved delineation of Sea Pen and Black Coral polygons has identified several locations outside the Area 2 closure where concentrations above the biomass threshold occur (Figure 7.100a.). There is limited stability in fishing pressure above the effort cut-off threshold within the Sea Pen (Figure 7.100.b) and Black Coral (Figure 7.100.c) polygons. There are areas of high fishing stability associated with the eastern portion of the Large Gorgonian Coral polygon but this does not coincide with catches above the biomass threshold of this VME. However, there is very limited fishing activity in the Area 2 "notch" in the northwestern side of the Area 2 closure where there is a high occurrence of catches above the biomass threshold for Large Gorgonian Coral (Figure 7.100.d). There are areas of high fishing stability overlapping with the Large-sized Sponge VME polygon along the northeastern and southwestern edges of the Area 2 closure but there is no occurrence of catches above the biomass threshold associated with these zones of high fishing activity (Figure 7.100.e). Given the occurrence of catches above the biomass threshold for Sea Pens, Black Coral and Large Gorgonians in parts of the VME polygons with very limited fishing stability, the expert assessment **proposes that two extensions to the Area 2 closure be put in place in the form of the closure of the "notch" on the northwestern side of the Area 2 to better protect Large Gorgonian Coral (Area 2a) and a northward extension of Area 2 to protect significant concentrations of Sea Pens and Black Coral (Area 2b)** (Figures 7.97, 7.100.a) and yield an improved overall protection for four VME taxa.


a)
New_Closures_WGESA_2020
Add
Remove
Current Closures
Significant Catches
Large Gorgonians (>= 0.6 kg)
Sponges (>= 100 kg)
Black Corals (>= 0.4 kg)
Boltenia (>= 0.35 kg)
Bryozoa (>= 0.2 kg)
Sea Pen (>= 1.3 kg)
Small Gorgonians (>= 0.2 kg)
VME Polygons
Large Gorgonians
Sponge
Black Coral
Boltenia
Bryozoans
Sea Pen
Small Gorgonians
Fishing Footprint
48°0'0"N
47°0'0"N
46°0'0"N
45°0'0"N
50°0'0"W
49°0'0"W
48°0'0"W
47°0'0"W
b)
Blk Cor Fishing (yrs > threshold)
10
1
c)
Sea Pen Fishing (yrs > threshold)
10
1
d)
Lg Gor Fishing (yrs > threshold)
10
1

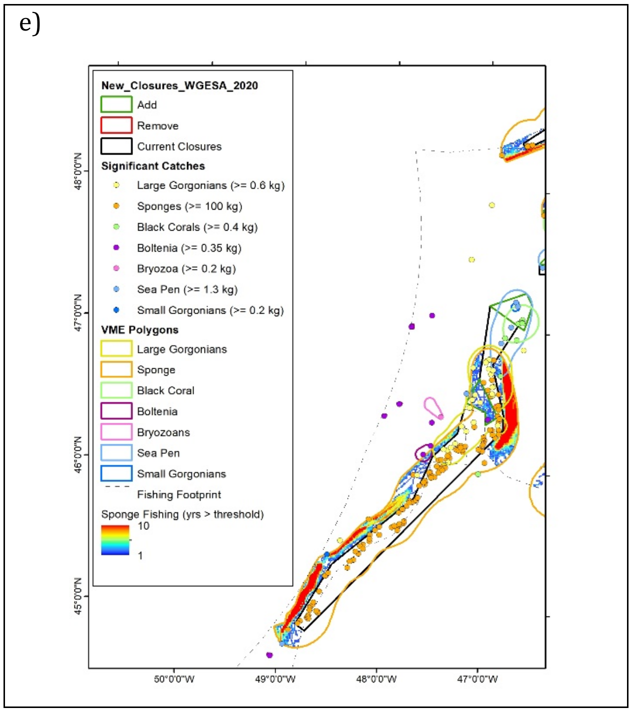


Figure 7.100. a) VME polygons and location of catches per RV tow above the biomass threshold values for VME taxa in proximity with the Area 2 Large-sized Sponge closure, showing the existing closure (in black) and proposed extensions (in green); b) overlay of fishing stability (years above the effort cut-off threshold) with the Black Coral polygons; c) overlay of fishing stability with the Sea Pen polygons; d) overlay of fishing stability with the Large Gorgonian Coral polygon; and e) overlay of fishing stability with the Large-sized Sponge polygons.

Area 3 and 13 Large-sized Sponge and Large Gorgonian Coral Closures

Although there have been changes to the VME polygons associated with Area 3 and 13 closures based on greater available data (NAFO 2020), the occurrence of VME concentrations above the biomass thresholds for both Large-sized Sponge and Large Gorgonian Corals generally coincide with these two closures (Figure 7.101). There is no occurrence of fishing activity above the appropriate effort cut-off thresholds for these two VME. As a result, expert assessment **concludes that no changes to Area 3 and Area 13 closures are necessary at this time.**

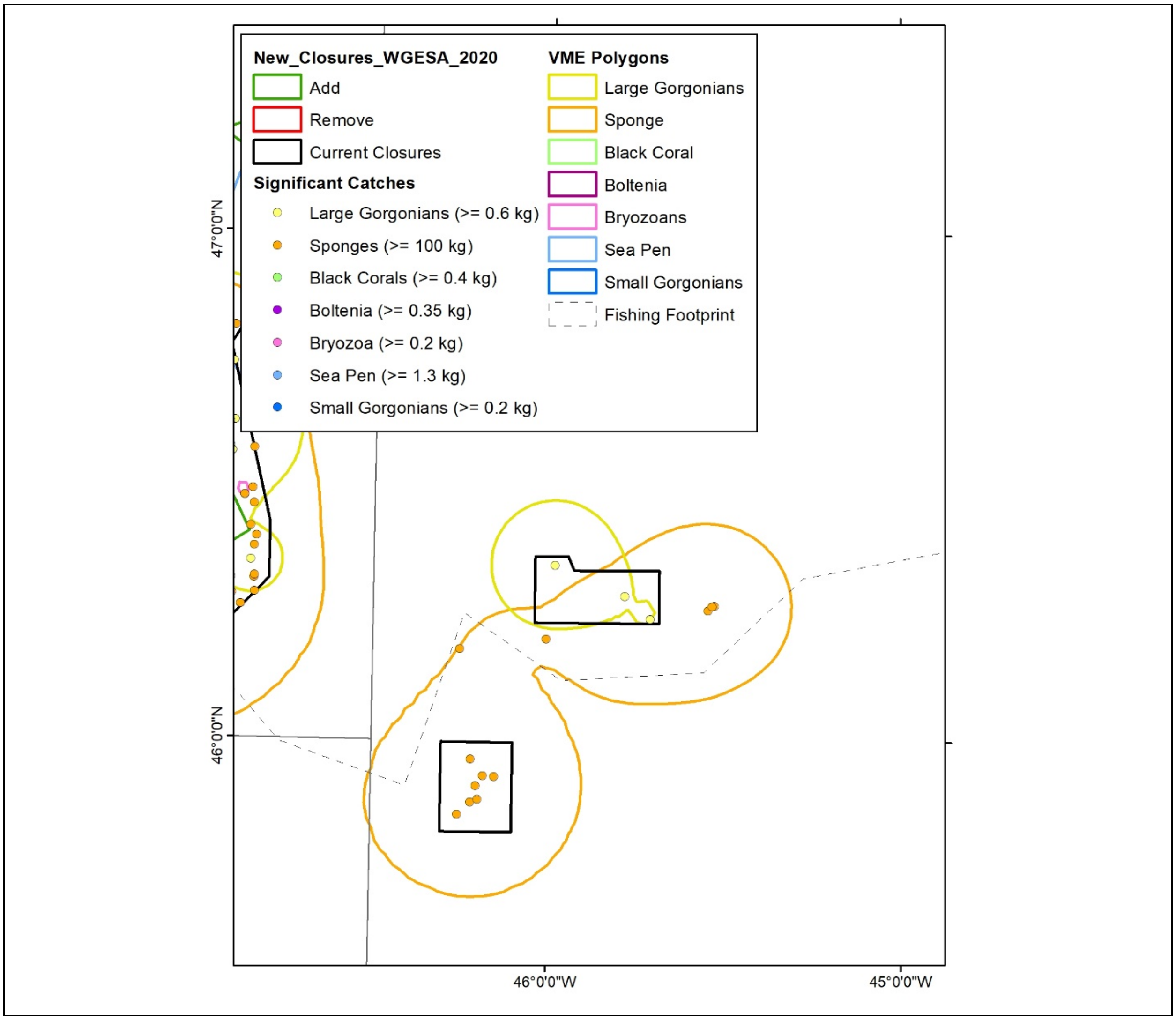


Figure 7.101. VME polygons and location of catches per RV tow above the biomass threshold values for Large-sized Sponge and Large Gorgonian Coral in proximity to Area 3 and Area 13 closures.

Areas 4-12 Flemish Cap and Sackville Spur Including Area 14

Eastern Flemish Cap Area 4 & 5 Large-sized Sponge and Large Gorgonian Coral Closures

There is one major area with high concentrations of Large Gorgonian Corals and two areas with high concentrations of Large-sized Sponges along the eastern portion of the Flemish Cap (Figure 7.102.a). There are two closures that capture the majority of catches above the biomass threshold in this portion of the Cap for both these VMEs but there are very few observations from scientific surveys between the two closures and the estimated VME polygons extend beyond existing closures (Figure 7.102.a). Overall fishing stability overlap with the Large Gorgonian Coral (Figure 7.102.b) and Large-sized Sponge (Figure 7.102.c) VME polygons is very limited and generally low (1-3 years). Furthermore, there is limited overall fishing activity by vessels using bottom-contact gear between Area 4 & 5 closures (Figure 7.102.d) likely owing to the steep topography and unsuitable bottom for trawling. As a result, the expert assessment **proposes that an extension of closures between Areas closures 4 & 5 (Area 4a) be implemented** to increase protection of Large Gorgonian Coral and Large-sized Sponge. Drift modelling has demonstrated that Areas 4 & 5 are important sources of larvae that are critical to ensuring connectivity among closures for these VMEs (Figures 7.97, 7.102.a). Furthermore, the proposed closure extension represents a zone of Flemish Cap with high functional and species diversity that is important for nutrient recycling and habitat provision (Section 7.b)iv. Benthic functional polygon boundaries).

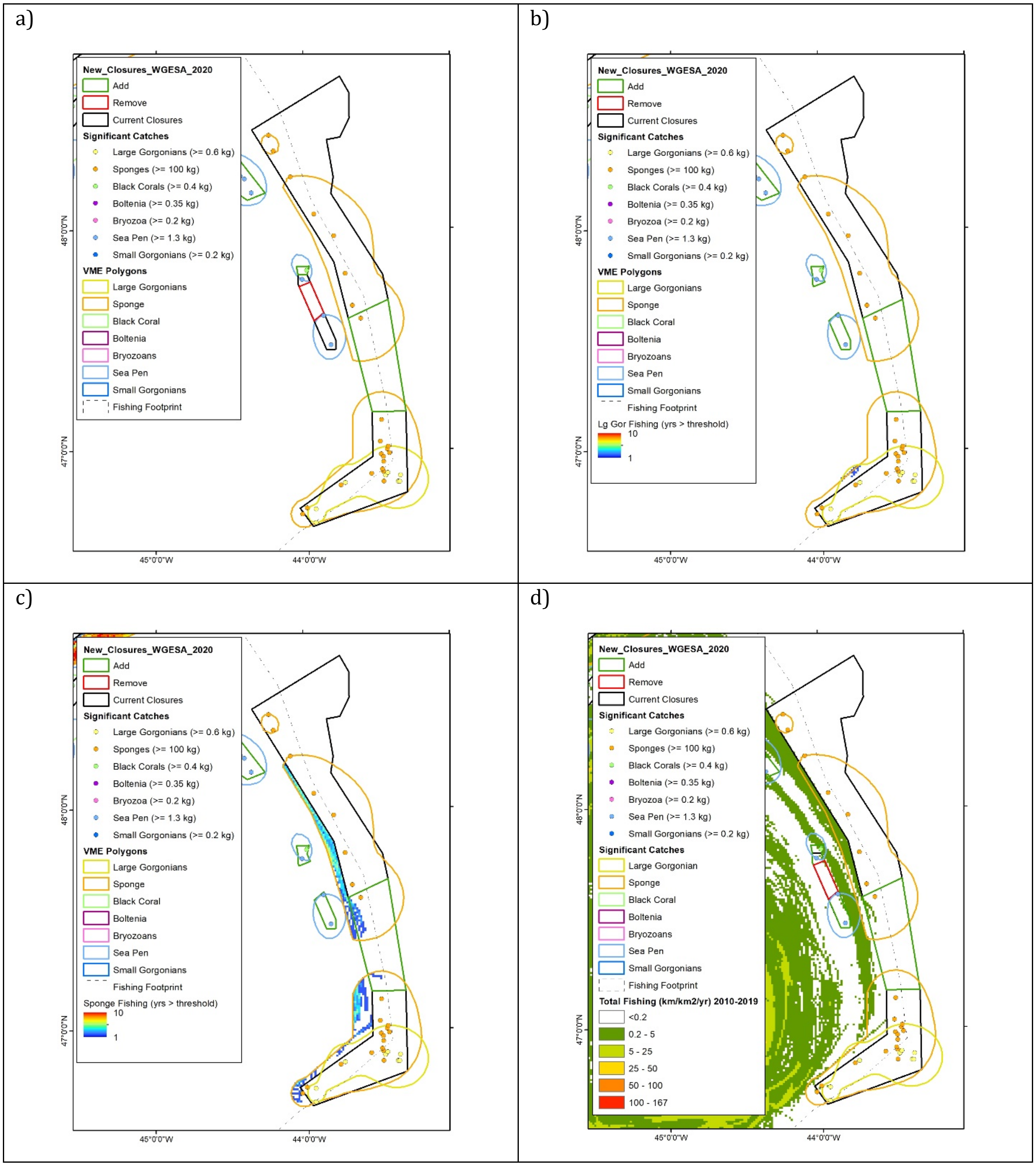
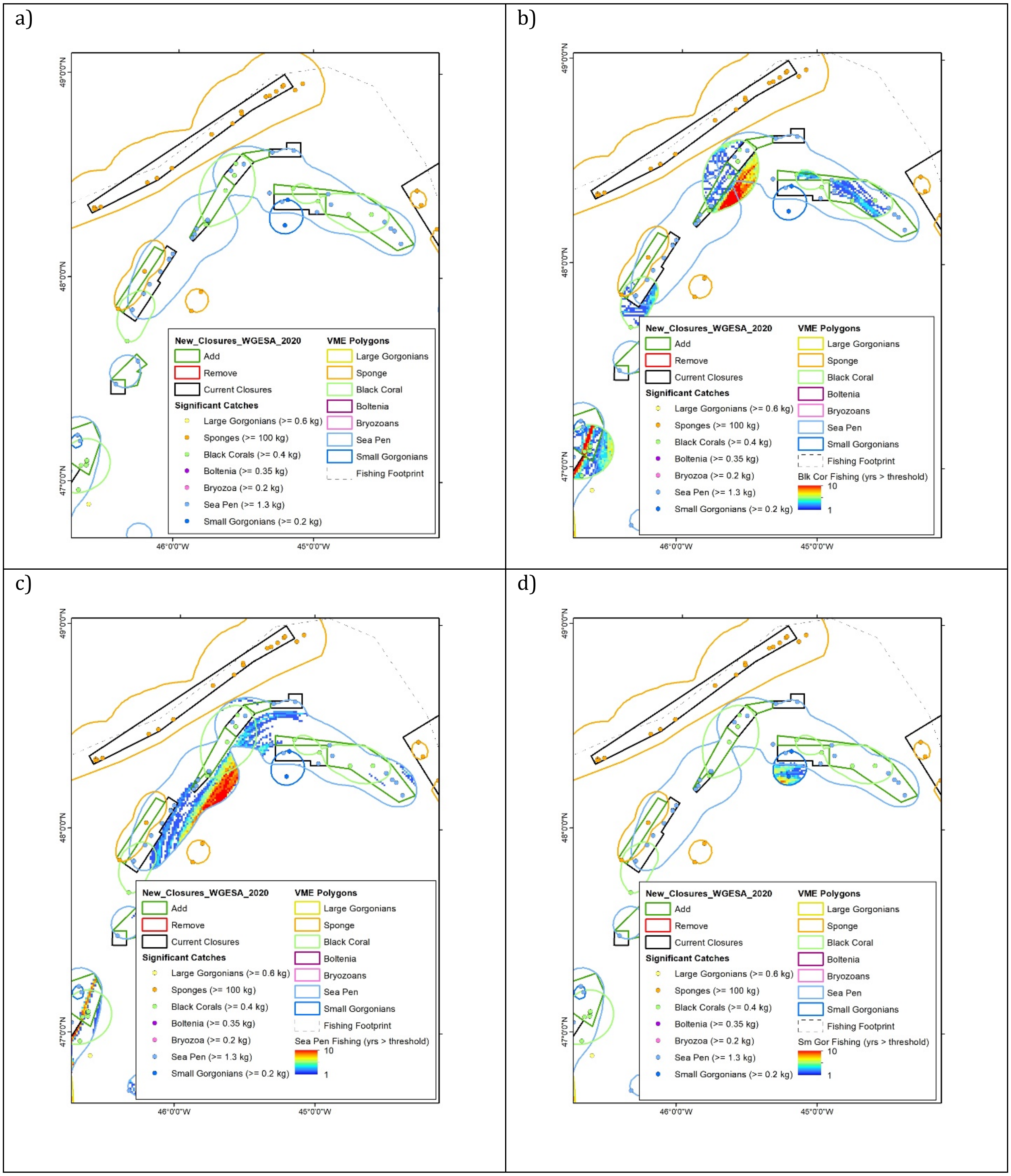


Figure 7.102. a) VME polygons and location of catches per RV tow above the biomass threshold values for VME taxa in proximity with the Areas 4 & 5 Large-sized Sponge and Large Gorgonian Coral closures, showing the existing closure (in black) and proposed extensions (in green); b) overlay of fishing stability (years above the effort cut-off threshold) with the Large Gorgonian Coral polygons; c) overlay of fishing stability with the Large-sized Sponge polygons; d) distribution of average fishing effort estimated from VMS data (2010-2019).

Northwestern Flemish Cap Area 6 to 12 Closures

Extensive VME polygons for Large-sized Sponges, Sea Pens, Small Gorgonian Corals and Black Coral have been identified on the northwestern portion of the Flemish Cap where there is an important closure for Large-sized Sponge (Area 6) and several small closures for Sea Pens (Areas 7-12) (Figure 7.103.a). There is extensive overlap among VME polygons for these four VME. Biophysical modelling has demonstrated the importance of existing closures in maintaining connectivity and resilience of VMEs but also highlights that the small size of some closures limits their capacity for self-retention and as sinks for recruitment (Wang *et al.*, 2020; Section 7.b)vi).

Existing closures provide protection for a high proportion of VME catches above the biomass threshold for each taxa but the review of closures has also identified many sites where these is currently little or no protection. Fishing stability above the effort cut-off threshold overlaps with the Black Coral VME polygon to the east of Area Closure but the intensity is low to moderate whereas the fishing stability associated with Black Coral in proximity to Area Closure 9 is high only in the southeastern portion of that polygon, and catches of Black Coral above the biomass threshold are only found outside existing closures in this Portion of the Cap correspond to areas with low fishing stability (Figure 7.103.b). A polygon for Small Gorgonian Corals is associated with Area Closure 7 and overlaps with moderate fishing stability (Figure 7.103.c). Sea Pens are broadly distributed in this part of Flemish Cap, and have a relatively high fishing effort cut-off threshold (4.3 km km^{-2} y^{-1}), but the overlap of areas of high fishing stability with Sea Pens polygons is limited to areas east of Area Closures 9, 10 and 11 (Figure 7.103.d). As a result, there is a high occurrence of catches above the biomass threshold for several VME outside many of the existing closures in areas with relatively low fishing activity that would benefit from enhanced protection (NAFO 2019). Catches of Large-sized Sponge above the biomass threshold have been identified to the northwest of Area Closure 6, and to the east and west of Area Closure 10 (Figure 7.103.e). Low levels of fishing stability are associated with Large-sized Sponge catches above the biomass threshold to the west or Area Closure 10 but the other two areas outside closures in which high catches of Large-sized Sponge are in areas with high levels of fishing stability. As a result of the limited overlap of high VME concentrations with fishing activity, the expert assessment **counsels for an eastward extension of Area Closure 7 to provide greater protection for Sea Pens and Black Corals (Area 7a); for the extension to Area Closures 8 and 9 (linking with Area Closures 8, 9 and 12) to provide a more continuous Closure to protect Sea Pens and Black Coral (Areas 8a and 9a) and improve connectivity; for a westward extension to Area Closure 10 to provide combined protection for Sea Pens and Large-sized Sponge (Area 10a); for a northeastward extension of Area Closure 11 to provide enhanced protection for Sea Pens (Area 11a)** (Figures 7.97, 7.103.a).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Significant Catches
Large Gorgonians (>= 0.6 kg)
Sponges (>= 100 kg)
Black Corals (>= 0.4 kg)
Boltenia (>= 0.35 kg)
Bryozoa (>= 0.2 kg)
Sea Pen (>= 1.3 kg)
Small Gorgonians (>= 0.2 kg)
VME Polygons
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Bryozoans
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Small Gorgonians
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Large Gorgonians (>= 0.6 kg)
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Bryozoa (>= 0.2 kg)
Sea Pen (>= 1.3 kg)
Small Gorgonians (>= 0.2 kg)
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Large Gorgonians
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Bryozoa (>= 0.2 kg)
Sea Pen (>= 1.3 kg)
Small Gorgonians (>= 0.2 kg)
VME Polygons
Large Gorgonians
Sponge
Black Coral
Boltenia
Bryozoans
Sea Pen
Small Gorgonians
Fishing Footprint
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Large Gorgonians (>= 0.6 kg)
Sponges (>= 100 kg)
Black Corals (>= 0.4 kg)
Boltenia (>= 0.35 kg)
Bryozoa (>= 0.2 kg)
Sea Pen (>= 1.3 kg)
Small Gorgonians (>= 0.2 kg)
VME Polygons
Large Gorgonians
Sponge
Black Coral
Boltenia
Bryozoans
Sea Pen
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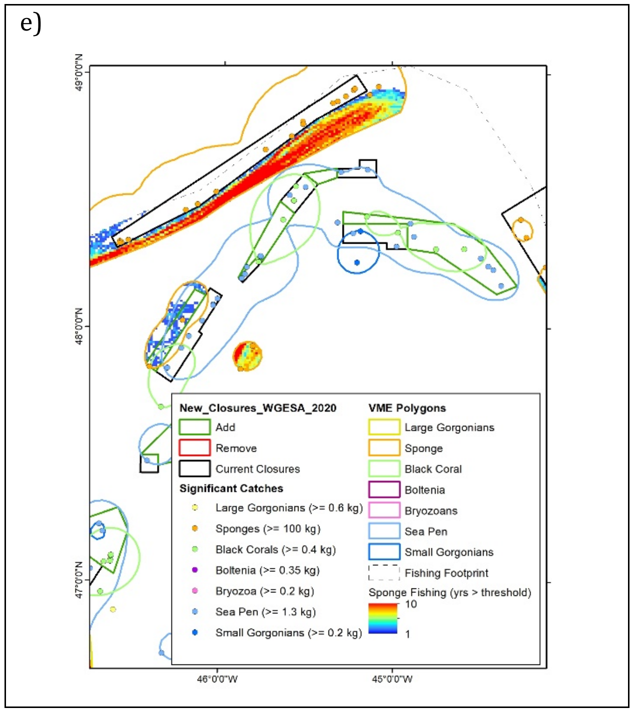


Figure 7.103. a) VME polygons and location of catches per RV tow above the biomass threshold values for VME taxa on the northwestern Flemish Cap (Area closures 6 to 12), showing the existing closure (in black) and proposed extensions (in green); b) overlay of fishing stability (years above effort cut-off threshold) with the Black Coral polygons; c) overlay of fishing stability with the Sea Pen polygons; d) overlay of fishing stability with the Small Gorgonian Coral polygon; and e) overlay of fishing stability with the Large-sized Sponge polygons.

Area 14 Sea Pen Closure

Area Closure 14 (Sea Pens) was established in January 2017 and re-opened to fishing in December 2018 (NAFO 2019). The Area 14 Closure had been based on results from the 2015 analysis (NAFO 2015) which had approximately half of the number of observations from the 2019 re-assessment of the closures (NAFO 2019), which resulted in a substantial reduction in the area of the VME polygon associate with Area Closure 14. However, there are strong indications of important concentrations of Sea Pen VME in the eastern portion of the Flemish Cap, to the west of Area Closure 5 (Large-sized Sponge) (Figure 7.104.a). There are low levels of fishing stability associated with these Sea Pen polygons, and catches of Sea Pen above the biomass threshold occur to the west of areas of low fishing activity (Figure 7.104b). Owing to importance of Area 14 to connectivity among areas of high Sea Pen concentration (Section 7.b)vi; figure 7.51) (Wang *et al.*, 2020), the expert assessment **counsels for the re-establishment of a modified Area 14 (Areas 14a and 14b) over areas of high Sea Pen concentrations in the eastern portion of the Flemish Cap** (Figures 7.97, 7.104.a).

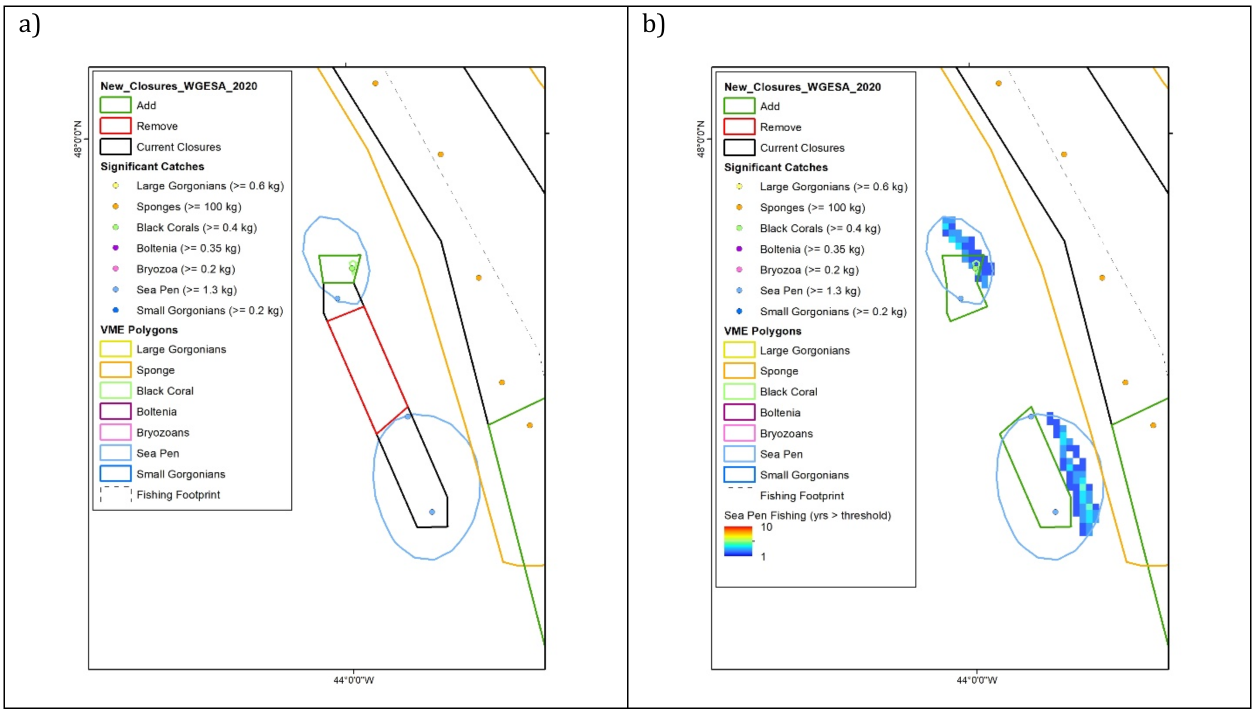


Figure 7.104 a) VME polygons and location of catches per RV tow above the biomass threshold values for Sea Pens associated with former Area Closure 14 showing the existing closure (in black), proposed extensions (in green) and reductions (in red); and b) overlay of fishing stability above the effort cut-off threshold with the Sea Pen polygons.

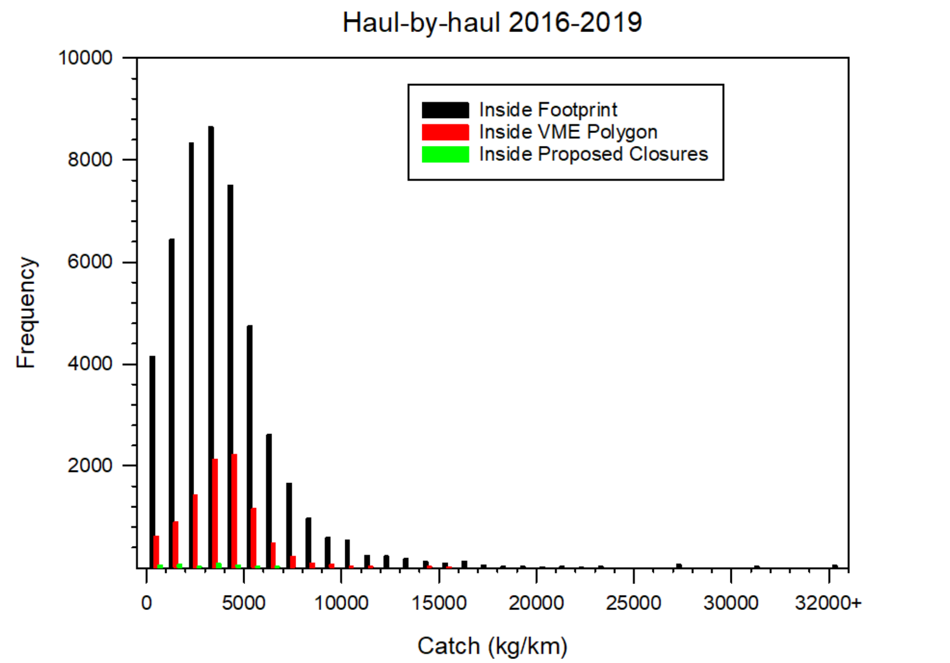
iv) Management Options – VME Protection, Fishery Activity and Catches

Re-assessment of the effectiveness of NAFO closed areas concluded that protection was inadequate for three VME taxa (Small Gorgonian Corals, Sea Quirts and Erect Bryozoans), poor for two VME taxa (Black Coral and Sea Pens), which implied that management action was considered essential, while two VME taxa (Large Gorgonian Corals and Large-sized Sponges) had incomplete protection but that management action was desirable but not essential (NAFO 2019). Relative protection of VME areal distributions and total biomass ranged from 0-61% and 0-94%, respectively (Tables 7.68, 7.69). Proposed extensions and modifications to existing closures and the implementation of three new closures (Section 7.e)iii) would result in an overall areal protection of 21-68% of VMEs, increases ranging from 4-55%, and overall biomass protection of 32-96%, increases ranging from 3-78% (Tables 7.68, 7.69). From an areal perspective, protection for Erect Bryozoans and *Boltenia* would remain poor; protection for Black Coral, Sea Pens, and Small Gorgonian Coral would be limited; and protection for Large Gorgonian Coral and Large-sized Sponges would be good. The proposed changes to closures would provide good protection of biomass for six VME taxa, with only Small Gorgonian Corals having limited protection of overall biomass. Together, increased protection of areal extent and overall biomass would represent highly important and substantial improvements to the current effectiveness of NAFO closed areas.

Improvements to VME protection must also be balanced against the potential constraints that would be imposed on the fisheries within the NRA. Based on the haul-by-haul data (Section 7.c; Sacau *et al.*, 2020) for the period 2016-2019, a total of 47492 km^2 over the entire NRA were fished and resulted in an associated catch (Figure 7.105). Total catch per effort ranged from 0.5 to 51536 kg km^{-1} (average: 4083). Of the area fished, 9468 km^2 overlapped with VME polygons (excluding closures), with total catch per effort ranging from 37 to 33872 kg km^{-1} (average: 4118). Of the area overlapping VMEs, only 366 km^2 overlapped with the proposed changes to existing closures (0.77% of total area fished), with total catch per effort ranging from 319 to 17146 kg km^{-1} (average: 4052).

The direct impact of the new closures to the total catches and to catches of five important fishery species are detailed in Table 7.70. Overall, approximately 28.5% of effort occurs in VME polygons while approximately 20% of total catches occur in VME polygons. Approximately 75% of the total effort occurs in areas that are fished for 10 years for all VME, and 65% of total catch is achieved in areas that are fished for all VME for 7 or more years. Most of the effort occurs in association with Large Gorgonian, Large-sized Sponge and Sea Pen VMEs. Overall catches are greatest in VME polygons for Large-sized Sponge, Sea Pens and Large Gorgonian Corals. The proposed closures would result in a 0.61% loss of total average effort and a 0.75% loss of total average catch. Consistent with the work of Sacau *et al.* (2020), the greatest fishery interaction with VMEs are associated with catches of Greenland halibut, Yellowtail flounder and redfish, followed by skate and cod (Table 7.70). Catch losses would be greatest for Greenland halibut (1.3% of Total NRA catch), and most likely associated with modifications to Sea Pen and Black Coral Closures (Table 7.70, Section 7.c)iv), and lowest for Cod (0.023%). The Redfish and mixed fisheries on the southwestern Tail of the Grand Bank interact most strongly with the Small Gorgonian Coral polygon (Table 7.70, Section 7.c)iv). The losses from the proposed changes to VME Closures could be compensated for with a very minor adjustment in the spatial distribution of fishing effort, and are very small relative to inter-annual changes in TACs associated with changes in population abundance.

a)



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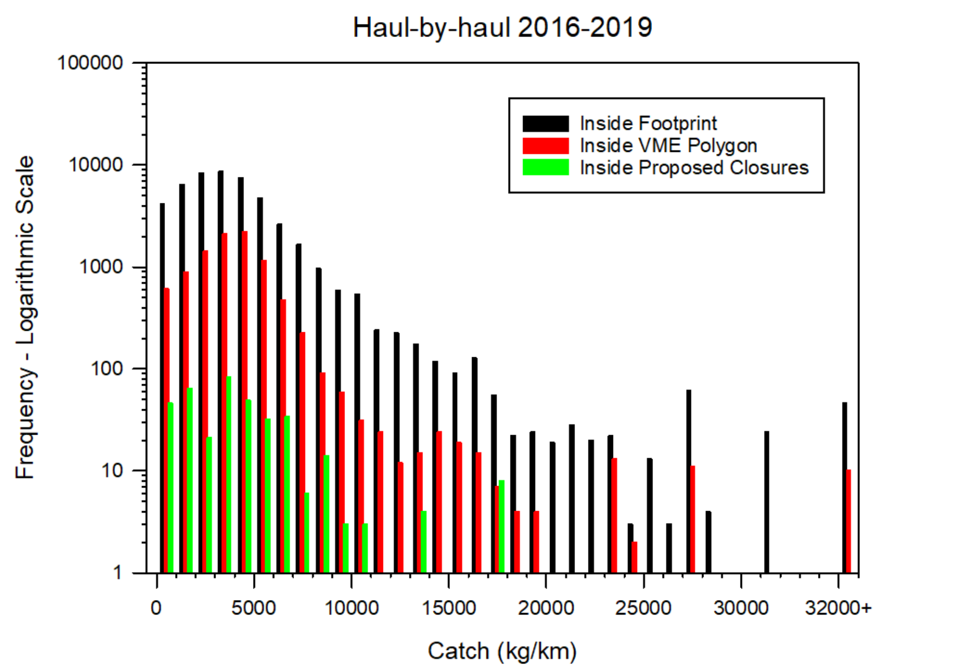

Figure 7.105. a) Frequency distribution of the square kilometres fished in relation to total catch per unit of tow (kg km^{-1}) in each square kilometre on a linear scale over the entire NRA (Inside footprint – black bars), inside VME polygons (red bars), and inside proposed extension and modifications to existing closures and inside proposed new closures; and b) Same as A but on a logarithmic scale. There are 70 square kilometres in the entire NRA, and 11 overlapping with VMEs, with catch per effort values exceeding 32 000 kg km^{-1}.

Table 7.68. Total area and percent of total area for VMEs within the polygons estimated from Kernel Density estimates, closed areas within the fishing footprint, conditionally protected outside fishing footprint, protected overall (sum of protected biomass inside and outside fishing footprint), and unprotected for existing closures (including Area 14 but excluding 3O closure) and existing + proposed closures.

Existing Closures
(excluding area 14, excluding 3O)

	VME Polygons	Closed Area		*Conditionally Protected		Protected Overall		Unprotected	
VME	Area (km²)	Area (km²)	Percent	Area (km²)	Percent	Area (km²)	Percent	Area (km²)	Percent
Black Coral	2,799	521	19%	0	0%	521	19%	2,278	81%
Bryozoans	3,498	5	0%	0	0%	5	0%	3,493	100%
Large Gorgonian Coral	5,415	2,918	54%	316	6%	3,234	60%	2,181	40%
Sea Pen	9,085	1,459	16%	1	0%	1,460	16%	7,625	84%
Sea Squirts (*Boltenia ovifera*)	4,081	0	0%	17	0%	17	0%	4,064	100%
Small Gorgonian Coral	4,756	84	2%	0	0%	84	2%	4,672	98%
Large-sized Sponges	26,011	10,163	39%	6,409	25%	16,572	64%	9,439	36%

Existing + Newly Proposed Closures

	VME Polygons	Closed Area		*Conditionally Protected		Protected Overall		Unprotected	
VME	Area (km²)	Area (km²)	Percent	Area (km²)	Percent	Area (km²)	Percent	Area (km²)	Percent
Black Coral	2,799	1,543	55%	0	0%	1,543	55%	1,256	45%
Bryozoans	3,498	690	20%	0	0%	690	20%	2,808	80%
Large Gorgonian Coral	5,415	3,346	62%	316	6%	3,662	68%	1,753	32%
Sea Pen	9,085	4,093	45%	1	0%	4,094	45%	4,991	55%
Sea Squirts (*Boltenia ovifera*)	4,081	856	21%	17	0%	873	21%	3,208	79%
Small Gorgonian Coral	4,756	1,752	37%	0	0%	1,752	37%	3,004	63%
Large-sized Sponges	26,011	11,483	44%	6,032	23%	17,516	67%	8,495	33%

Table 7.69. Total biomass and percent of total biomass for VMEs within the polygons estimated from Kernel Density estimates, closed areas within the fishing footprint, conditionally protected outside fishing footprint, protected overall (sum of protected biomass inside and outside fishing footprint), and unprotected for existing closures (including Area 14 but excluding 3O closure) and existing + proposed closures.

Existing Closures
(excluding area 14, excluding 3O)

	VME Polygons	Closed Area		*Conditionally Protected		Protected Overall		Unprotected	
VME	Biomass (kg)	Biomass (kg)	Percent	Biomass (kg)	Percent	Biomass (kg)	Percent	Biomass (kg)	Percent
Black Coral	10,441	2,615	25%	0	0%	2,615	25%	7,826	75%
Bryozoans	65,567	4	0%	0	0%	4	0%	65,563	100%
Large Gorgonian Coral	133,448	97,157	73%	19,808	15%	116,965	88%	16,483	12%
Sea Pen	100,244	32,900	33%	24	0%	32,924	33%	67,320	67%
Sea Squirts (*Boltenia ovifera*)	41,572	0	0%	215	1%	215	1%	41,357	99%
Small Gorgonian Coral	3,351	61	2%	0	0%	61	2%	3,290	98%
Large-sized Sponges	276,985,425	212,834,753	77%	44,191,066	16%	257,025,819	93%	19,959,606	7%

Existing + Newly Proposed Closures

	VME Polygons	Closed Area		*Conditionally Protected		Protected Overall		Unprotected	
VME	Biomass (kg)	Biomass (kg)	Percent	Biomass (kg)	Percent	Biomass (kg)	Percent	Biomass (kg)	Percent
Black Coral	10,441	8,002	77%	0	0%	8,002	77%	2,439	23%
Bryozoans	65,567	50,856	78%	0	0%	50,856	78%	14,711	22%
Large Gorgonian Coral	133,448	99,651	75%	19,808	15%	119,460	90%	13,988	10%
Sea Pen	100,244	64,272	64%	24	0%	64,296	64%	35,948	36%
Sea Squirts (*Boltenia ovifera*)	41,572	24,635	59%	215	1%	24,850	60%	16,722	40%
Small Gorgonian Coral	3,351	1,067	32%	0	0%	1,067	32%	2,285	68%
Large-sized Sponges	276,985,425	244,258,553	88%	20,875,096	8%	265,133,649	96%	11,851,776	4%

Table 7.70. Percent of total effort (2010-2019, no discrimination among fisheries) and percent of total average catch (2016-2019, discriminating key fishery species) overlapping with VME polygons. Percentages represent values relative to total effort and total catch over the entire NRA. Current refers to Existing Closures (excluding Area 14 and 3O Coral Closures); Current+ Proposed refers to Existing and Proposed Closure Modifications. Note that estimates of percent effort and percent catch for individual VME taxa do not take into account overlap with other VME taxa. All VMEs combined allows for calculations of percent of total effort and percent of total average catch without double counting overlapping VMEs.

Percent of Effort from VMEs	All VMEs	Black Coral	*Boltenia*	Bryozoans	Small Gorgonian Coral	Sea Pen	Large Gorgonian Coral	Sponge
All fisheries								
Percent Effort Current	28.494	0.676	2.670	1.445	2.594	4.079	10.283	9.842
Percent Effort Current + Proposed	27.884	0.515	2.572	1.409	2.573	3.777	10.071	9.828
Percent Difference	-0.610	-0.161	-0.098	-0.036	-0.021	-0.302	-0.212	-0.014

Percent of Catch from VMEs	All VMEs	Black Coral	*Boltenia*	Bryozoans	Small Gorgonian Coral	Sea Pen	Large Gorgonian Coral	Sponge
All Fisheries								
Percent Catch Current	20.106	1.422	2.632	2.552	2.674	4.158	3.375	5.876
Percent Catch Current + Proposed	19.354	1.255	2.588	2.548	2.549	3.792	3.135	5.814
Percent Difference	-0.752	-0.166	-0.044	-0.005	-0.125	-0.366	-0.239	-0.062
Cod								
Percent Catch Current	5.752	0.053	0.535	0.331	3.975	0.089	0.314	0.562
Percent Catch Current + Proposed	5.729	0.053	0.530	0.325	3.972	0.087	0.305	0.561
Percent Difference	-0.023	0.000	-0.005	-0.006	-0.003	-0.002	-0.009	-0.002
Greenland Halibut								
Percent Catch Current	39.132	3.157	0.383	0.004	2.344	13.098	1.767	23.404
Percent Catch Current + Proposed	37.822	2.592	0.383	0.004	2.342	11.939	1.589	23.347
Percent Difference	-1.310	-0.566	0.000	0.000	-0.001	-1.159	-0.178	-0.057
Redfish								
Percent Catch Current	21.213	1.054	9.429	0.313	2.441	2.087	6.281	1.566
Percent Catch Current + Proposed	20.561	1.054	9.379	0.313	2.256	1.907	5.942	1.459
Percent Difference	-0.652	-0.001	-0.050	0.000	-0.185	-0.180	-0.339	-0.107

Skate								
Percent Catch Current	15.942	0.068	3.359	11.105	0.090	0.190	1.553	0.330
Percent Catch Current + Proposed	15.706	0.064	3.216	11.061	0.080	0.176	1.511	0.327
Percent Difference	-0.236	-0.004	-0.143	-0.043	-0.010	-0.014	-0.042	-0.003
Yellowtail flounder								
Percent Catch Current	28.692	0.000	4.936	24.018	0.003	0.010	0.148	0.007
Percent Catch Current + Proposed	28.154	0.000	4.869	23.552	0.000	0.009	0.142	0.007
Percent Difference	-0.539	0.000	-0.067	-0.465	-0.003	-0.002	-0.007	0.000

v) Seamounts

The UN General Assembly (UNGA) resolution 59/25 calling for urgent action to protect VMEs from destructive fishing practices in areas beyond national jurisdiction (ABNJ) was adopted in 2004 (A/RES/59/25 https://undocs.org/en/A/RES/59/25). RFMOs responded promptly and on January 1 of 2005, NEAFC closed Hecate and Faraday Seamounts, the Altair Seamounts and the Antialtair Seamounts to bottom trawling and fishing with static gear (NEAFC 2004). In 2006, UNGA resolution 61/105 was adopted (https://undocs.org/A/RES/61/105), elaborating on a series of actions to be taken by States and RFMOs for the protection of VMEs. Effective January 1, 2007, both SEAFO and NAFO introduced closures to protect seamounts in accordance with those UNGA resolutions. SEAFO, an area with a large number of seamounts, closed 7 areas with seamounts, including one area with 10 seamounts known to occur (http://www.fao.org/fishery/vme/24238/170275/en). NAFO closed the Newfoundland Seamounts, the New England Seamounts, the Corner Rise Seamounts, and Orphan Knoll following a review of seamounts in the NAFO Convention Area (Kulka *et al.*, 2007). The Fogo Seamounts were later identified and closed effective the first of January, 2009. Both the Corner and the New England Seamount chains extend into the Western Central Atlantic Fishery Commission (WECAFC) mandate area. In 2016 WECAFC assigned the status of Vulnerable Marine Ecosystem (VME) to Corner Seamounts, New England Seamounts, Wyoming Seamounts and Congress and Lynch Seamounts bordering the NAFO Convention Area. No further changes to the NAFO Seamount closures were made until 2017 when the boundaries of the New England Seamount Chain were extended, effective January 1, 2018, to connect across to the EEZ of the United States of America (NAFO 2018).

In 2019, in response to request for review of the areas closed to protect VME in NAFO, WG-ESA concluded that the available information supported the continued designation of these areas as VMEs (NAFO 2020) and proposed new boundaries for the Corner Rise Seamounts (Figure 7.106, Area 4) and Newfoundland Seamounts (Figure 7.106, Area 2) to maintain connectivity across the seamount chains and to improve the protection of vulnerable seamounts in the NRA. As those recommendations have not been adopted yet, WG-ESA has taken the opportunity to undertake a more extensive review of the seamounts in the NAFO Areas Beyond National Jurisdiction. The sequence of events elaborated on above has resulted in an uneven approach to seamount protection with some seamounts in a local area protected and others of similar depth left outside the Seamount closures. Here we have used the time since the 2019 review to systematically review all of the closed areas to ensure a consistency of approach and have made proposals that should reduce the need for further revision unless new information emerges.

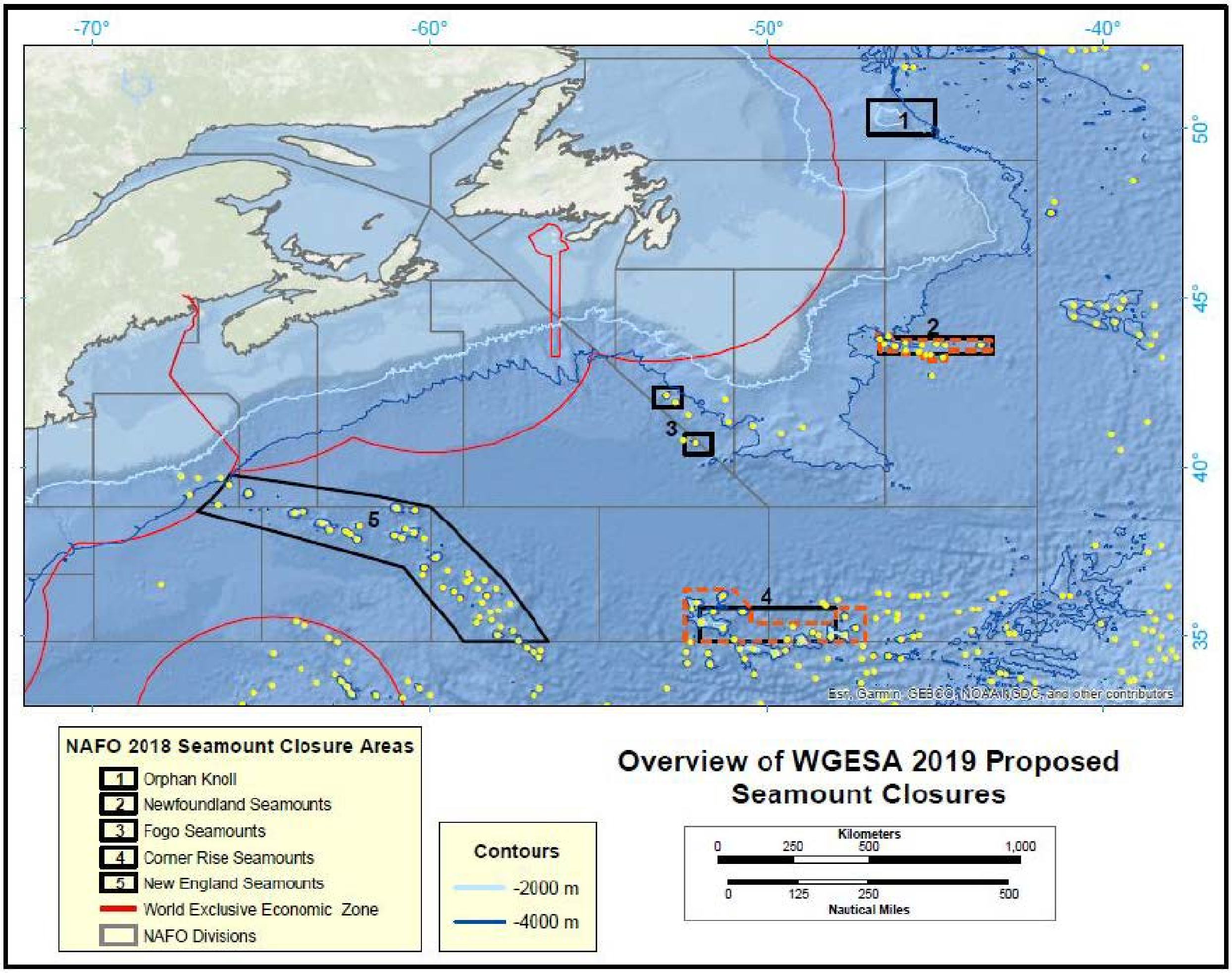

Figure 7.106. Location of the five (5) seamount areas in NAFO with closures indicated in black outline (NAFO 2021). Recommended changes in 2019 (NAFO 2020) to Areas 2 (Newfoundland Seamounts) and 4 (Corner Rise Seamounts) are indicated by orange dashed line. Yellow dots represent seamounts (source Kim and Wessel, 2011). Reprinted from NAFO (2020).

New Information on VMEs in the Seamount Closures

Since the last seamount assessment in 2019 (NAFO 2020), new information on VMEs in the seamounts from the NRA has been published supporting the designation of these areas. A new species of sponge, *Tedania* (*Tedaniopsis*) *rappi*, of 25 cm (width) x 15 cm (height), collected during the Canadian mission HUD2010-029 and the British RRS Discovery Cruise DY081 has been described in the Orphan Seamount within the Orphan Knoll closed area between 3000 and 3450 m depth (Ríos *et al.*, 2021). This sponge was found on rock, and 39 specimens were recorded on the transect (11 515 m length). Other sponges, such as the genus *Geodia*, considered VME Indicator taxa (NAFO 2021), were found associated with the same habitat. The FAO Guidelines (FAO, 2009) include “Uniqueness or rarity – an area or ecosystem that is unique or that contains rare species whose loss could not be compensated for by similar areas or ecosystems. These include: habitats that contain endemic species; habitats of rare, threatened or endangered species that occur only in discrete areas; or …” as a characteristic of a VME. Hence this unique population of sponge can be considered a VME indicator, and the seamount a VME habitat.

Additionally, Lapointe *et al.* (2020) have described the megabenthic assemblages in the lower bathyal (700 – 3 000 m) on the New England and Corner Rise Seamounts based on 34 dives occurred from 2003 to 2014 on 17 seamounts/peaks and over 400 hours of bottom time video. Depth, temperature, position along the chain and substrate composition were the major factors correlated with the assemblage composition. The shallowest depth samples were characterized by several coral species, such as the gorgonians *Placogorgia* sp., *Muriceides* sp., and *Acanella arbuscula* and the black coral *Parantipathes larix*, whereas some corals observed deeper than 2 500 m included the black coral *Bathypathes* sp. and the gorgonian *Paragorgia johnsoni*. They observed several sponges, mainly hexactinellids, and some species of corals deeper than 3000 m depth, however, these data were not included in the analysis as they were abyssal in nature. This new information provides continued support for the designation of these areas as VMEs and provides new information that VME indicator taxa can be found deeper than 3 000 m depth.

Information Used to Identify Seamounts in the NAFO ABNJ

Our primary source for the identification of seamounts is the publication by Kim and Wessel (2011) (NAFO 2020). They used altimetry-derived gravity data available at that time to identify morphological features extracted from the geometry of the contours (base dimensions, height etc.). A similar database by Yesson and colleagues (2011) was cross-referenced but was not used as the primary source of information as its scope was different from our purposes and some of their seamount locations have been shown to be invalid from the NEREIDA multibeam surveys (NAFO 2012). For the Fogo Seamounts area, a geological publication (Pi-Piper *et al.*, 2007) used in our previous reports (NAFO 2012) took precedence over both of the global databases.

The 2019 General Bathymetric Chart of the Oceans (GEBCO) was used to draw the bathymetric contour lines to inform decisions on polygon boundaries. The 2019 ESRI Ocean Basemap (https://www.arcgis.com/home/item.html?id=5ae9e138a17842688b0b79283a4353f6) was used as background layer.

Fogo Seamount Chain

The Fogo Seamounts are located on oceanic crust in the central North Atlantic Ocean, southwest of the Grand Bank and form a broad zone of basaltic volcanoes that parallels the transform margin. This zone is narrowest in the northwest and widens to 200 km in the southeast. This pattern differs from the narrow linear arrangement of a typical seamount channel, such as the Newfoundland and New England Seamounts. The largest seamounts have official names (after the ships that came to the aid of the Titanic). Other geological seamounts may be buried or are otherwise low features. Most of the Fogo seamounts are deeper than 2 000 m depth.

In 2012, WG-ESA provided additional information derived from geological work (Pi-Piper *et al.*, 2007) on the Fogo Seamounts and other unprotected seamounts in the chain south of the Tail of Grand Bank (Figure 7.107), but did not propose boundaries for their protection. The current closures on the Fogo Seamounts (Figure 7.108, red boxes) only protect three seamounts between 3 272 and 3 404 m depth (A, B and E in Figure 7.108). There are 4 other seamounts in this area that have peaks in shallower waters (2530-2899 m; Figure 7.108 legend) but that are not currently protected; another three (3) have similar peak depths. We have cross-compared the location of seamounts from Pi-Piper *et al.* (2007; Figure 7.108) with the most current bathymetry of the area (Figure 7.108) to resolve the bathymetry of their seamounts W, X, Y, and EE (Figure 7.108) of which they felt were possible seamounts based on the poor bathymetry they had at that time. **To complete the protection of seamounts on the Fogo Seamount Chain WG-ESA proposes boundary changes to the current closures to protect the seamounts shallower than 4000 m depth** (Figure 7.108, yellow outline) identified by Kim and Wessel (2011) and Pe-Piper *et al.* (Figure 7.108). This would protect 10 seamounts ranging in peak depth from 2 530 m to 3 892 m (Figure 7.108, legend).

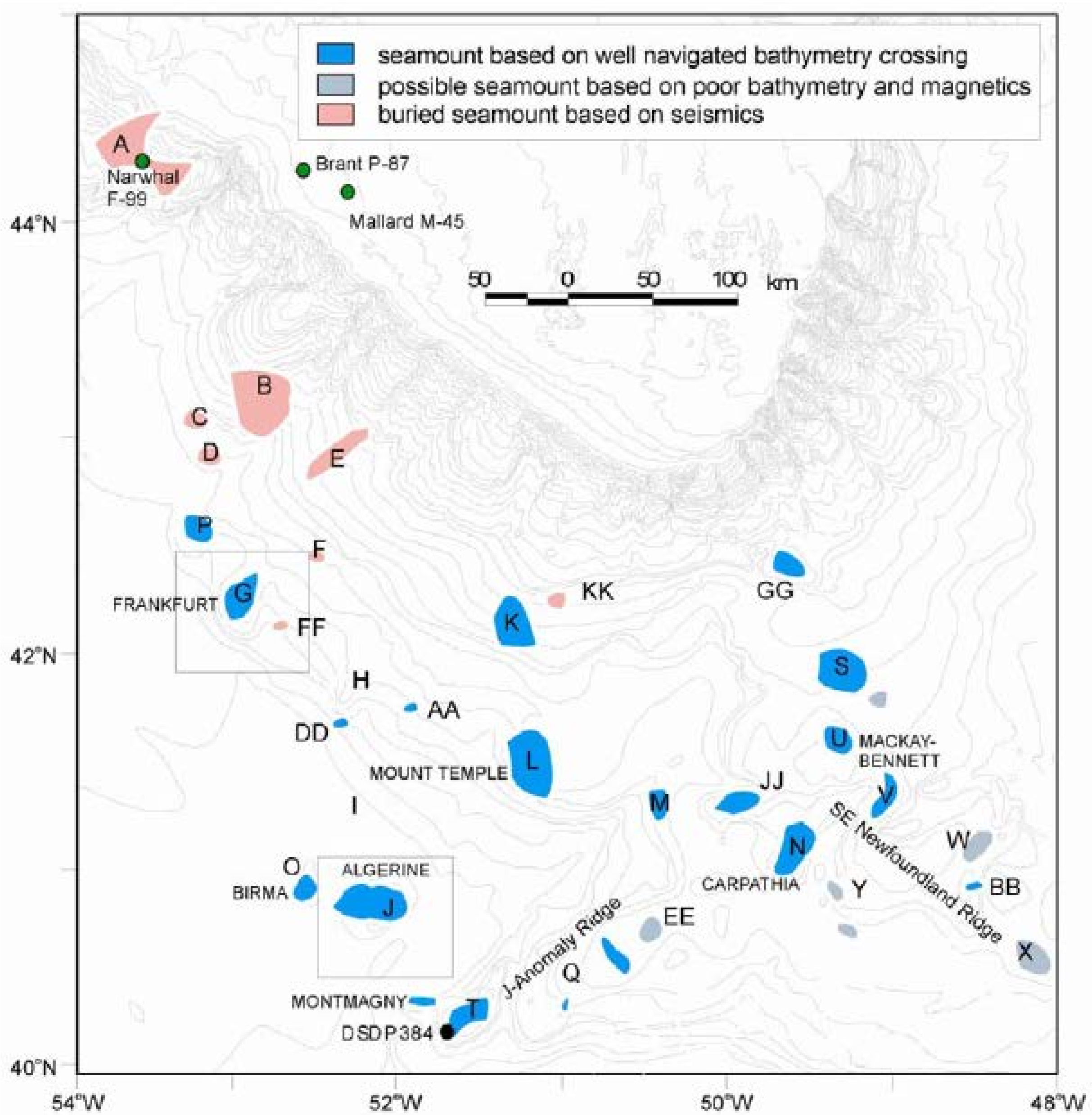

Figure 7.107. Map of the Fogo Seamount Chain south of the Tail of Grand Bank. Modified from Pe-Piper *et al.* (2007). Largest seamounts have official names (after the ships that came to the aid of the Titanic). Other geological seamounts may be buried or are otherwise low features. Letter codes refer to Table 2 of GSC Open File 5182 which lists sources of data. Reprinted from NAFO (2012).

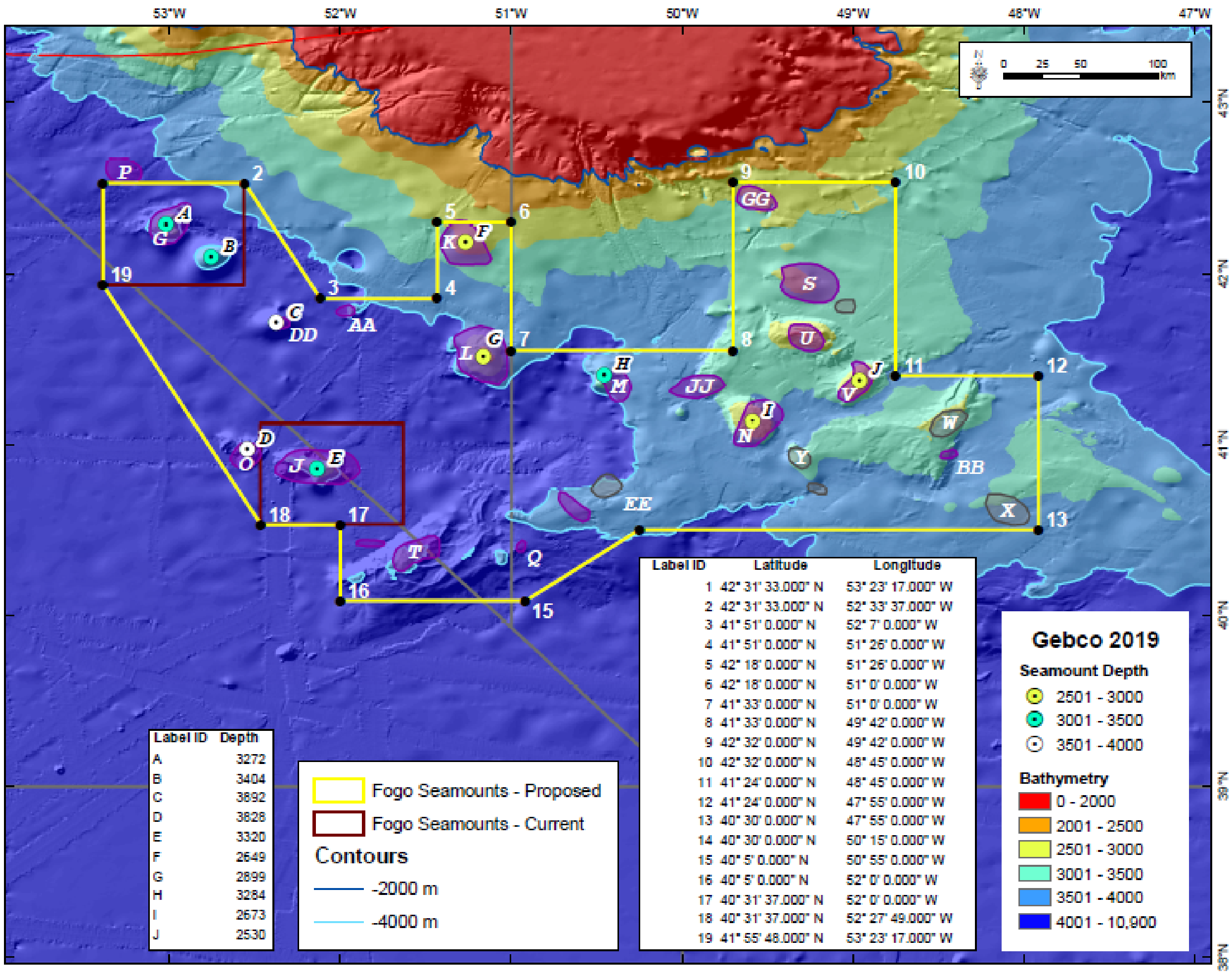

Figure 7.108. Close up of the current closed area to protect VMEs on the Fogo Seamounts (red outline; Fogo Seamounts I and 2 - NAFO 2021), with proposed boundary changes to capture the unprotected seamounts in the chain (yellow outline). Circles (A – J indicate seamounts identified by Kim and Wessel (2011) and colour-coded by peak depth, whereas purple and grey polygons, and associated lettering, indicate seamounts and possible seamounts identified by Pe-Piper *et al.* (2007) and modified from Figure 2). Light blue lines represents the 4000 m depth contour and the dark blue line indicates the 2 000 m depth contour. Associated co-ordinates for the new boundary and feature depths are listed.

<u>Newfoundland Seamount Chain</u>

The Newfoundland seamounts were volcanically active in the late Cretaceous period and are found east of the Tail of Grand Bank. Named seamounts include Shredder and Scruntion. The current closure (Figure 7.109) includes seamounts with peaks ranging from 2 446-3 756 m. There are three other seamounts in this depth range that were not within the boundaries of the current closure (seamounts C, L and P of Figure 7.109 have a depth range of 3 192-3 617 m). To ensure consistency in approach, **WG-ESA proposes boundary revisions that to ensure inclusion of 15 seamounts in the Newfoundland Seamount Chain with peak depths ranging between 2 446 and 3 756 m**.

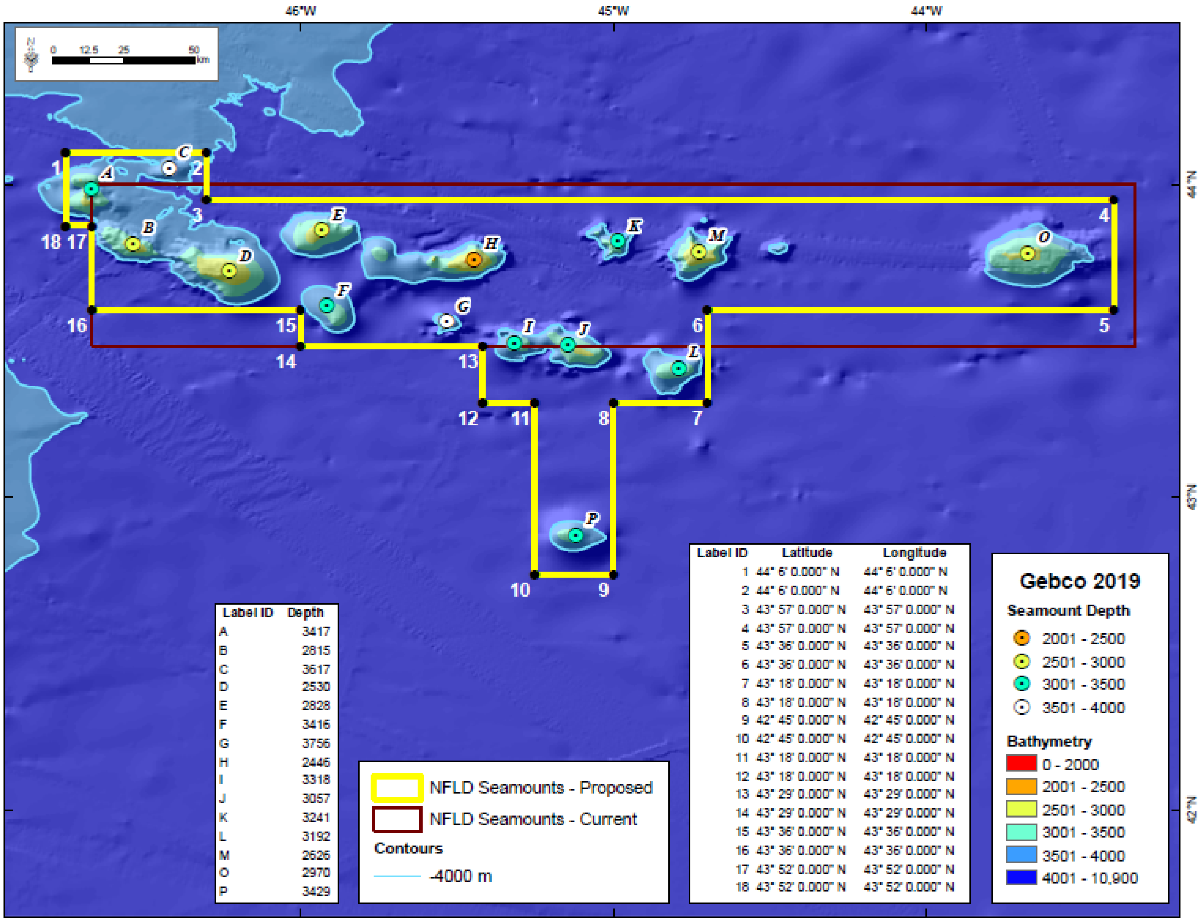

Figure 7.109. Close up of the current closed area to protect VMEs on the Newfoundland Seamounts (red outline), with proposed boundary changes to capture the unprotected seamounts of similar peak depths in the seamount chain (yellow outline). Circles (A – P) indicate seamounts colour-coded by depth (source Kim and Wessel 2011). The light blue line represents the 4 000 m depth contour. Associated co-ordinates for the new boundary and peak depths are listed in the legends.

Corner Rise Seamount Chain

The Corner Rise seamounts are the shallowest seamounts in the New England – Corner Rise Seamount system, rising from the sea floor to approximately 1 000 m depth or higher and cover approximately 1270 km^2 in area from peaks above 2 000 m depth. As noted above, they form a linear feature. Named seamounts within the Corner Rise Seamount chain include: Bean Seamount, Caloosahatchee Seamount with Milne-Edwards Peak, Verrill Peak, Castle Rock Seamount, Corner Seamount with Goode Peak and Kukenthal Peak, Justus Seamount, MacGregor Seamount, Rockaway Seamount, Yakutat Seamount. Some of these peaks fall outside of the NAFO Convention Area. The 2019 proposed boundaries (NAFO 2020) accepted by the Scientific Council included 18 seamounts ranging in depth from 913-3 319 m (the area to the west of a vertical line south from point 8 in Figure 7.110). To ensure consistency in approach, **WG-ESA counsels that the boundary proposed in the Corner Rise Seamount area (NAFO 2020) be extended to the east to include the 7 seamounts ranging in peak depth from 2 747-3 881 m** (Figure 7.110, legend). This revision includes all seamounts identified by Kim and Wessel (2011) within the approximate peak depth range of the protected seamounts within the previously accepted closure out to the eastern boundary of the Convention Area (Figure 7.110). We included seamount Y with a peak depth of 3 881 m and seamount X with a peak depth of 3 640 m, as this is within the depth range of seamounts in the proposed boundary revisions for the Fogo Seamounts (see above). There are many other seamounts in the Corner Rise Seamount Chain towards the eastern portion of the NAFO Convention Area, however these all have peaks below 4 000 m (Figure 7.110).

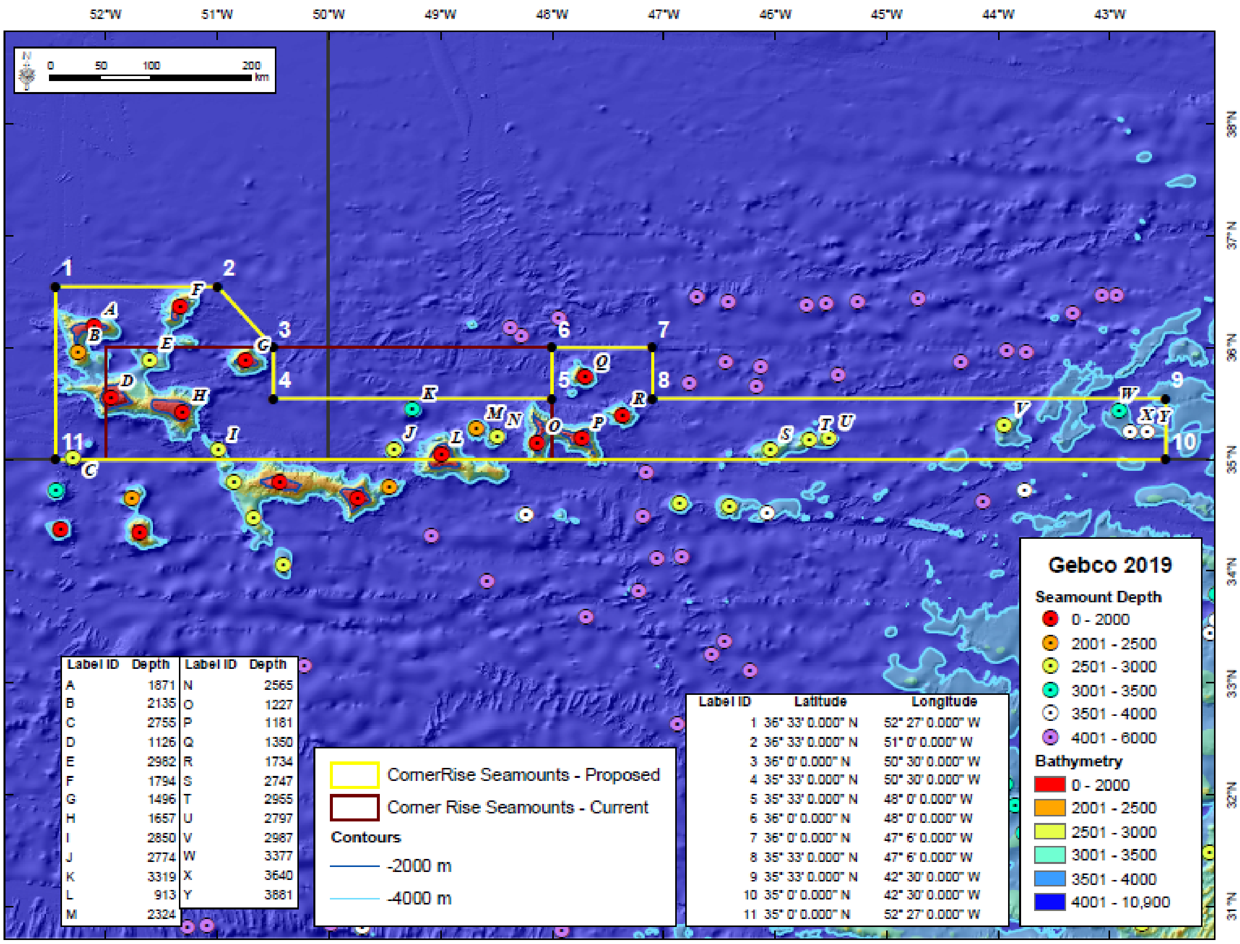

Figure 7.110. Close up of the current closed area to protect VMEs on the Corner Rise Seamounts (red outline), with proposed boundary changes to capture the unprotected seamounts nearby shallower than 4 000 m depth (yellow outline). The area outlined in yellow to the west of a vertical line extending south from point 8 was previously accepted by Scientific Council (NAFO 2020). Circles (A – Y) indicate seamounts (Kim and Wessel 2011) shallower than 4 000 m depth. The light blue line represents the 4 000 m depth contour. Associated co-ordinates for the new boundary and peak depths are listed. Note that the area south of 35N falls within the WECAFC area and those seamounts have been separately closed by that RFMO/A.

Survey in the Remainder of the NAFO Convention Area

If accepted, the proposed changes to the boundaries for the seamount closures would provide complete protection for the seamounts in the Fogo, Newfoundland and Corner Rise Seamount Chains; the Orphan Knoll having adequate coverage with the original closure, and the New England Seamount Chain being fully protected in the 2017 revision (NAFO 2018) and the establishment of the Northeast Canyons and Seamounts Marine National Monument within USA waters. The New England Seamount Chain is 40-60 km in width with summit depths from 900 to 2 300 m below the surface (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Geophysical Data Center, 2006. 2-minute Gridded Global Relief Data (ETOPO2v2) http://www.ngdc.noaa.gov/mgg/fliers/06mgg01.html). The depth range of these seamount peaks range from 913 m in the Corner Rise Seamount proposal to 3892 m in the Fogo Seamount Chain proposal.

In order to apply a consistent approach across the remaining areas of the NAFO Convention Area in ABNJ we examined any seamounts or seamount-like features that we not included in the above proposals and that had a peak depth < 4 000 m. We first reviewed those seamounts identified by Kim and Wessel (2011) that met this depth criterion and then we did a survey of the whole Convention Area in ABNJ using the updated 2019 GEBCO bathymetry to identify seamounts or seamount-like features within the depth range. In order to provide more information from the bathymetric data, the slopes greater than 6.4°, that are indicative of steep flanks and therefore potential VME elements (Murillo *et al.*, 2011), were also highlighted for review.

Seamounts Outside of Existing and Proposed Closures

All of the seamounts that had peaks < 4 000 m were north of Orphan Knoll. Seven seamounts shallower than 4 000 m depth were identified by Kim and Wessel (2011) and/or by using the 2019 GEBCO bathymetry in the NAFO Divisions 1F, 2HJ, and 3K. **WG-ESA proposes the implementation of seven seamount closures in the NAFO Convention Area in ABNJ north of Orphan Knoll**.

Figure 7.111 represents and overview of these closure proposals whereas Figures 7.112 to 7.116 are close ups of each Area. Area 1 in Division 2H (2H East) was identified by Kim and Wessel (2011) and the updated bathymetry shows a mountainous region with the summit at 3 056 m (Figure 7.112). Areas 2 (2J East 1) and 3 (2J East 2) from Figure 7.111 are shown in detail in Figure 7.113. These seamounts are in Division 2J and include one identified by Kim and Wessel (2011) and one identified using the 2019 GEBCO bathymetry. For both areas the boundaries were informed by the presence of steep slopes (Murillo *et al.*, 2011). The shallowest depth in Area 2 is 2 925 m (A in Figure 7.113) and 3 451 m in Area 3 (B in Figure 5.5.8). Area 4 (1F West) from Figure 7.111. in Division 1F captures a seamount identified by Kim and Wessel (2011) and the steep flanks associated with the feature (Figure 7.114). This seamount has a peak at 2 795 m depth. Other potential areas to the north of Area 4 (Figure 7.111) did not show steep flanks and were not included. Area 5 (3K North) in Division 3K captures a seamount identified by Kim and Wessel (2011) (Figure 7.114). This seamount has a peak at 3 580 m depth. Lastly, Areas 6 (1F East 1) and 7 (1F East 2) in Division 1F near the eastern boundary of the Convention Area (Figure 7.111) are shown in close up in Figure 7.115. Area 6 shows a steep-sided pinnacle identified from the 2019 GEBCO bathymetry with a peak at 2 429 m. Area 7 was identified by Kim and Wessel (2011) and also includes steep flank elements (Figure 7.115) with a peak depth of 2 734 m. Collectively these closures would protect seven (7) seamounts or seamount-like features with peaks ranging from 2 429 m to 3 580 m, and provide protection to all known seamounts in the NAFO Convention Area ABNJ with peaks < 4 000 m.

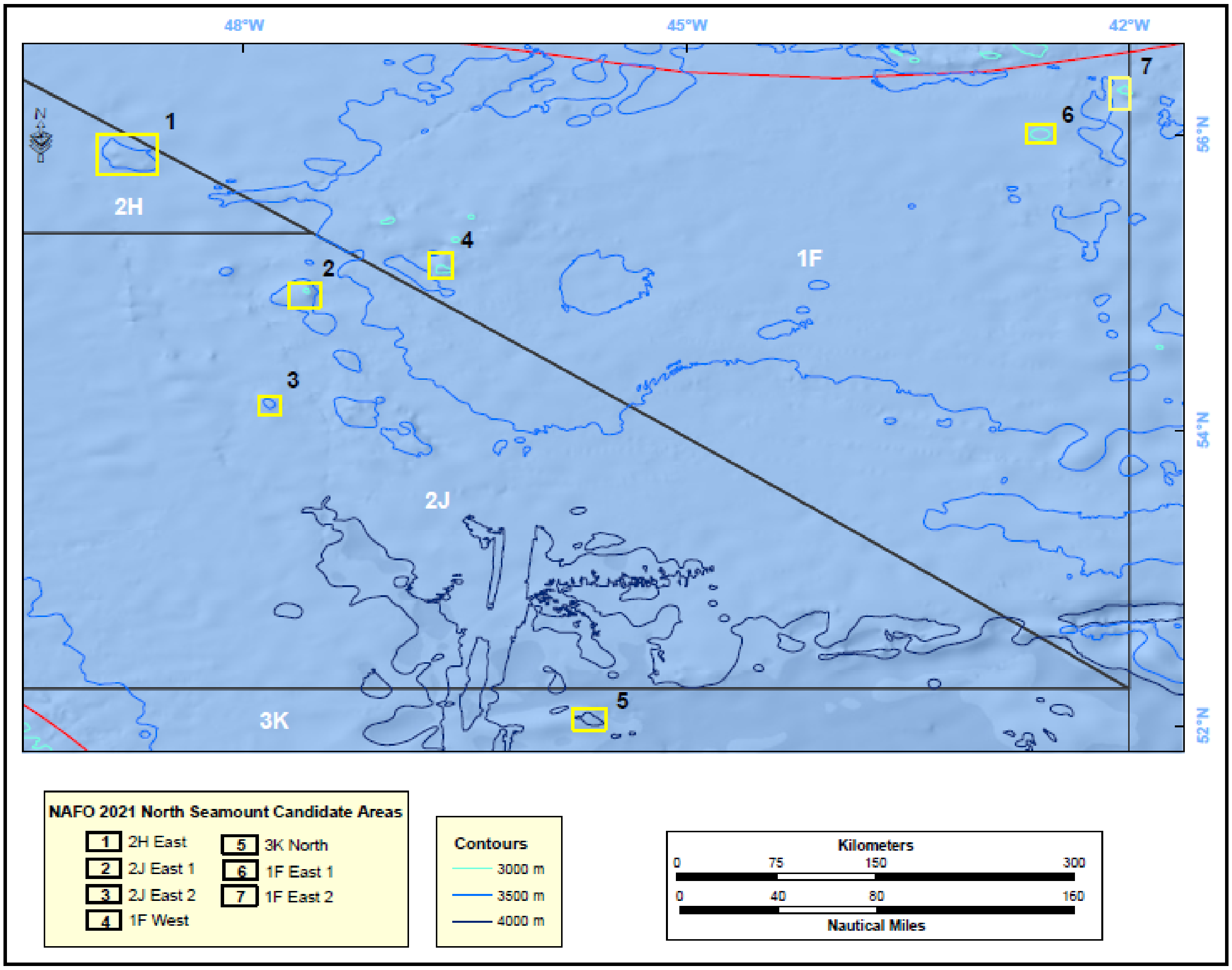

Figure 7.111. Location of the proposed closures (yellow boxes) to protect the 7 individual and tentative seamounts in NAFO Divisions 1F, 2HJ, and 3K. The EEZ of Greenland (north) and Canada (southwest) are outlined in red. Detailed maps are provided in Figures 7.112 to 7.116.

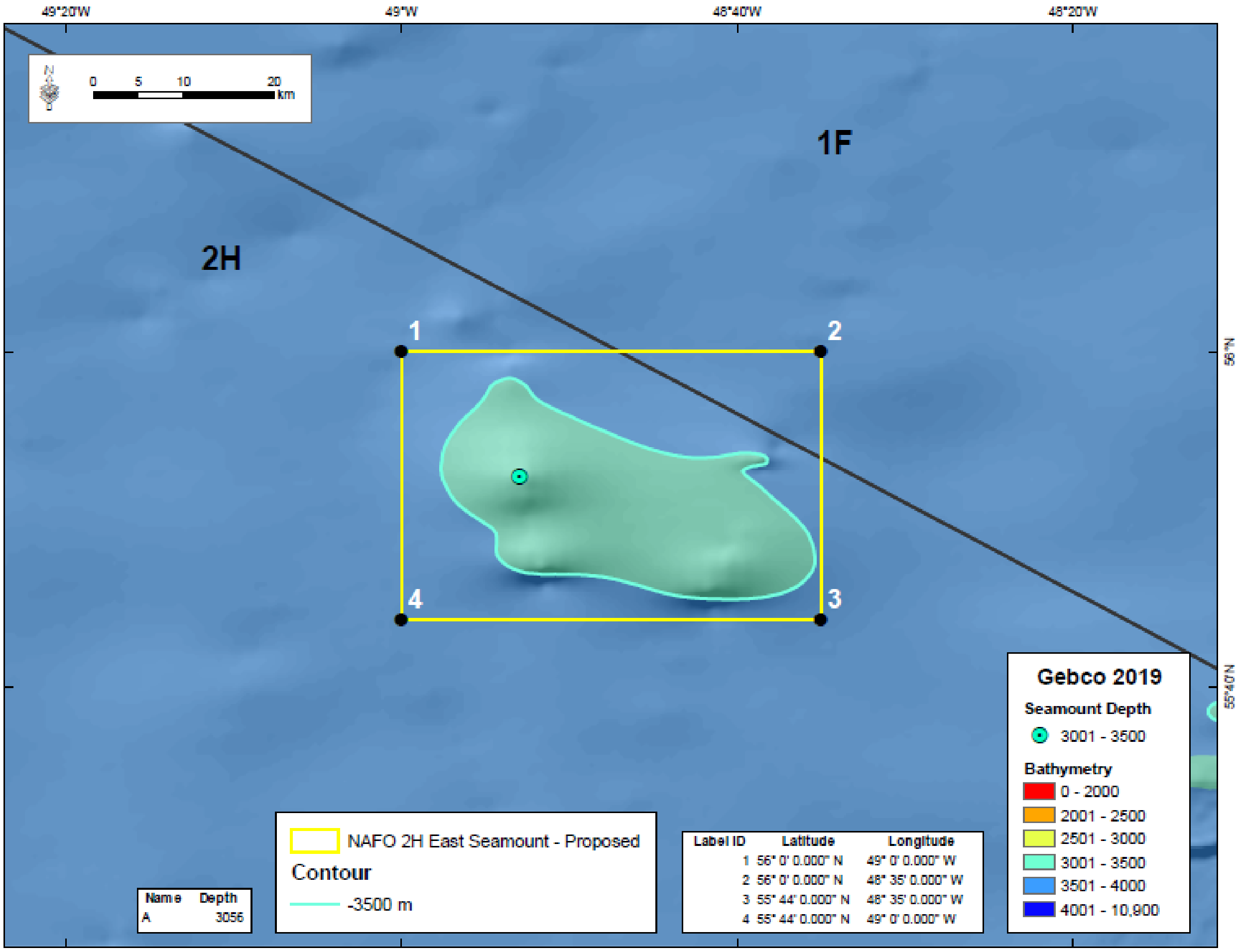

Figure 7.112. Close up of Area 1 (2H East) from Figure 7.111. Proposed individual seamount closures to capture the unprotected seamount shallower than 4 000 m depth in NAFO Division 2H (source Kim and Wessel 2011).

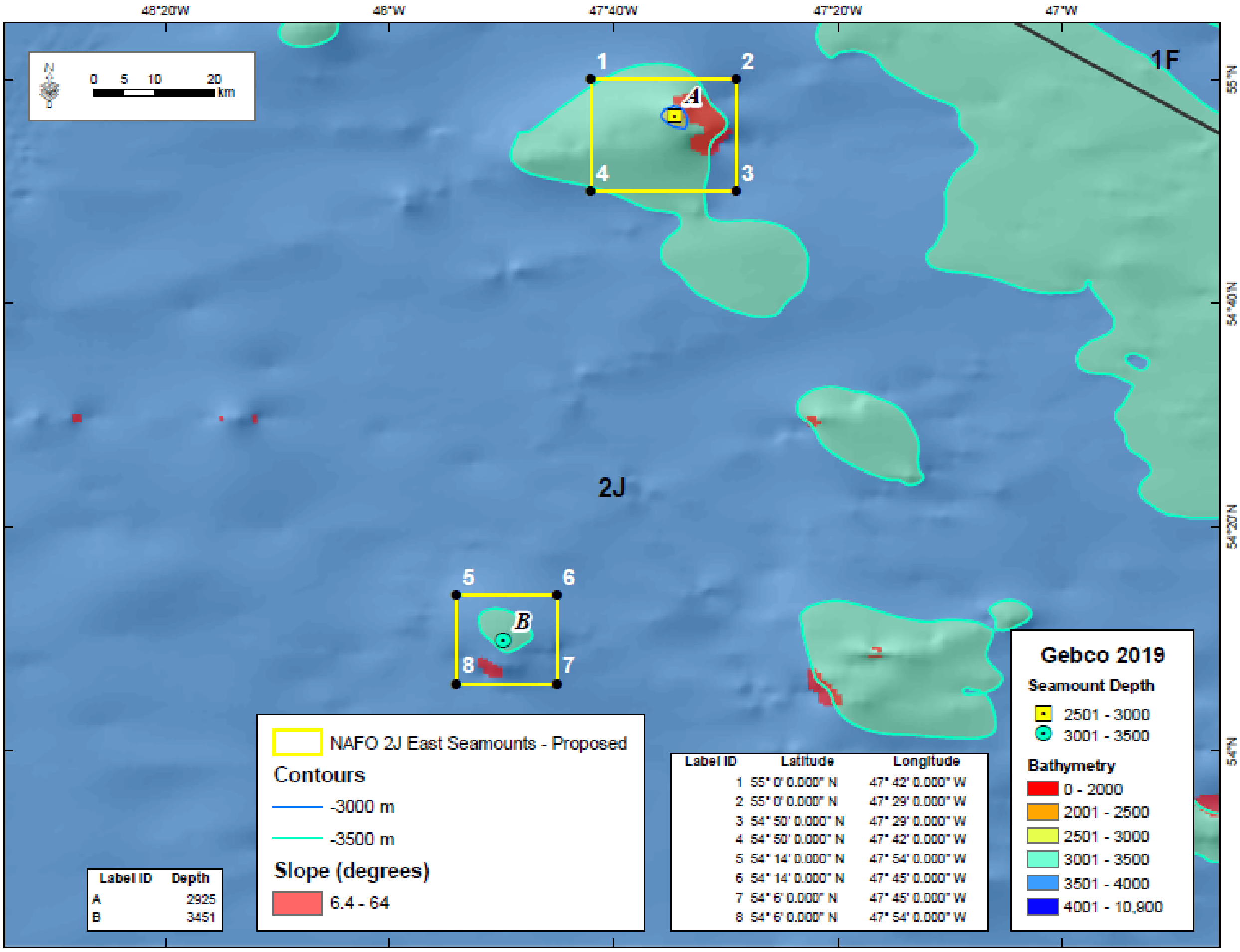

Figure 7.113. Close up of Areas 2 (2J East 1) and 3 (2J East 2) from Figure 7.111. Proposed seamount closures to capture the unprotected seamounts shallower than 4000 m depth in the NAFO Division 2J. The Seamount A (yellow square) represents a tentative seamount based on the 2019 GEBCO whereas Seamount B (blue circle) was identified by Kim and Wessel (2011). Red areas highlight slopes greater than 6.4°. Depth contours for 3 500 m are highlighted.

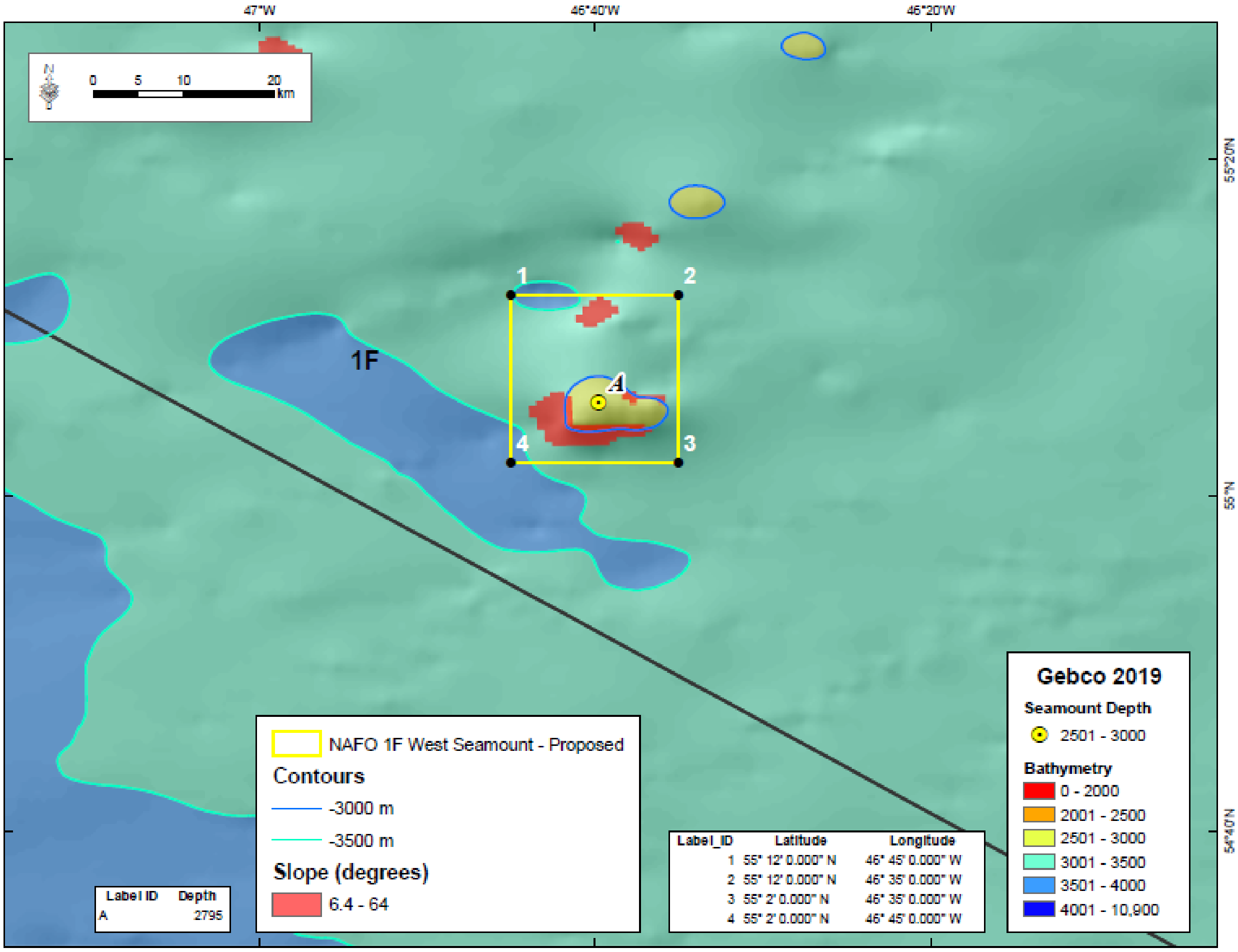

Figure 7.114. Close up of Area 4 (1F West) from Figure 7.111. Proposed seamount closures to capture the unprotected seamount shallower than 4 000 m depth in the NAFO Division 1F. Seamount A (yellow circle) represents a tentative seamount based on the 2019 GEBCO. Red areas highlight slope greater than 6.4°. Depth contours for 3 500 and 3 000 m are highlighted.

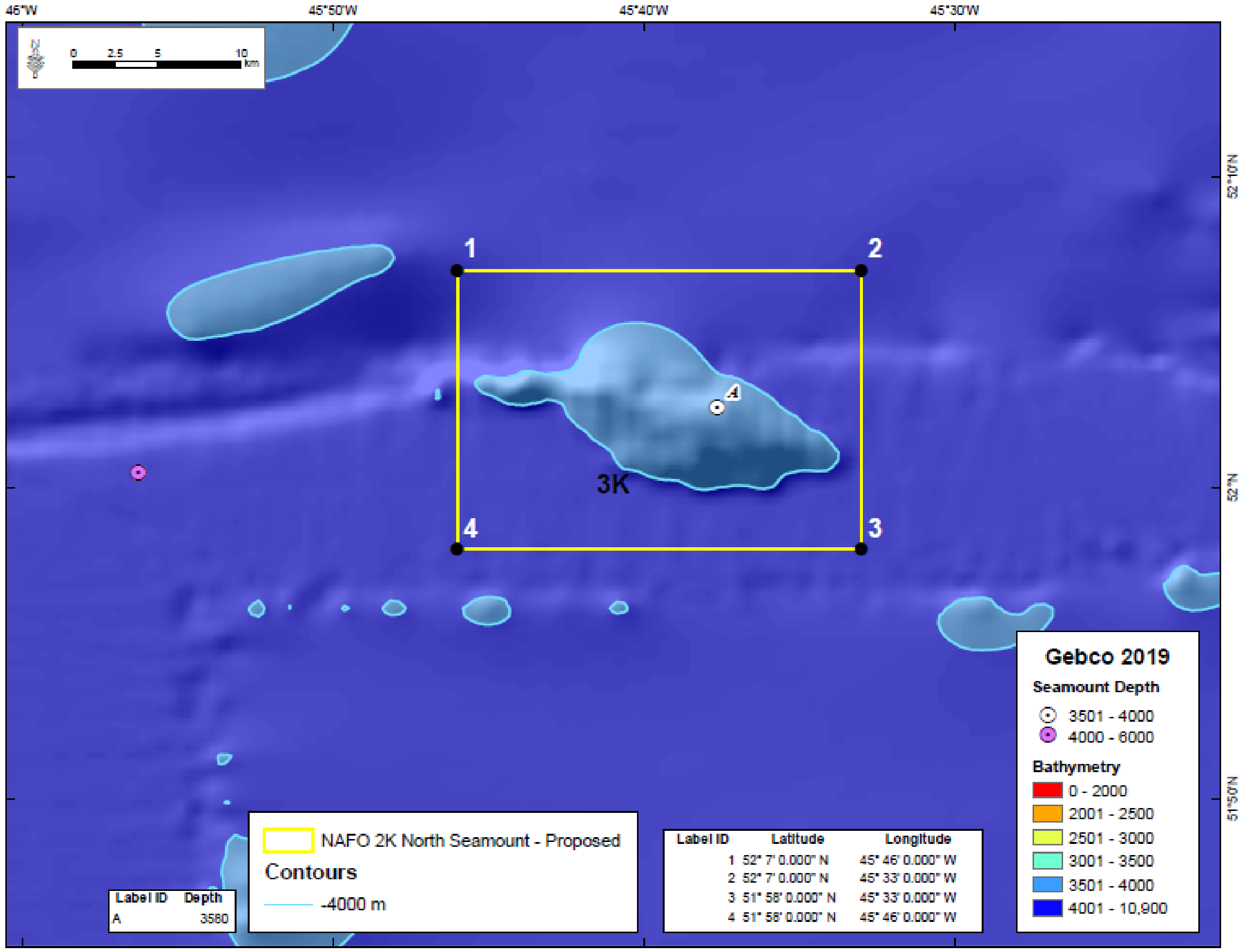

Figure 7.115. Close up of Area 5 (3K North) from Figure 7.111. Proposed individual seamount closure to capture the unprotected seamounts shallower than 4 000 m depth in the NAFO Division 3K (source Kim and Wessel 2011). Depth contours for 4 000 m are highlighted.

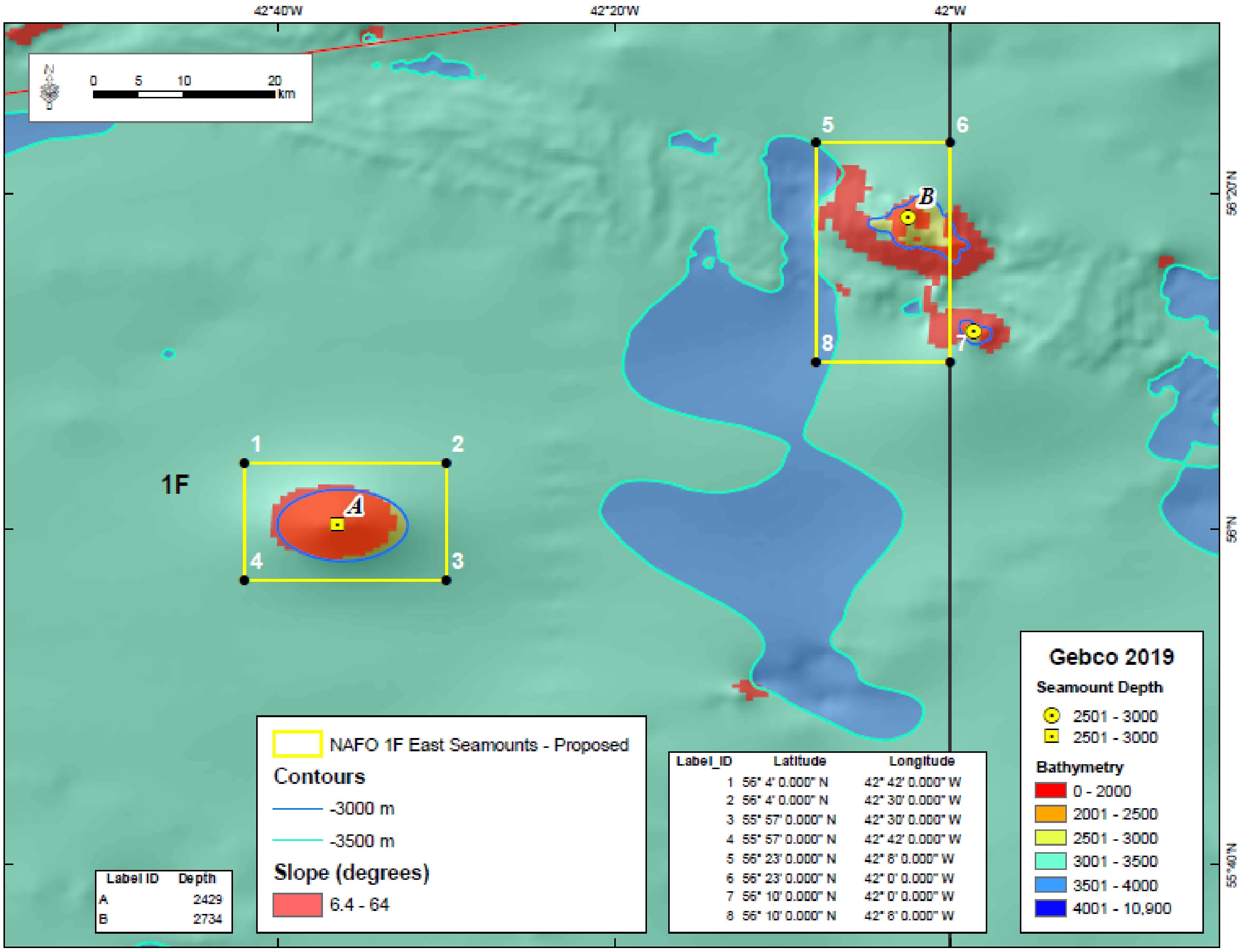

Figure 7.116. Close up of Areas 6 (1F East 1) and 7 (1F East 2) from Figure 7.111. Proposed seamount closures to capture the unprotected seamount shallower than 4 000 m depth in NAFO Division 1F. Seamount A (yellow square) represents a tentative seamount based on the 2019 GEBCO whereas Seamount B (yellow circle) was identified by Kim and Wessel (2011). Red areas highlight slope greater than 6.4°. Depth contours for 3 000 and 3 500 m are highlighted.

Summary of revisions to seamount closures in the NAFO Convention Area

An overview of all the seamount closure modifications and new additions can be consulted in Figure 7.117. WG-ESA has conducted a systematic revision of all seamounts known to occur in the NAFO Convention Area in ABNJ. A review of current closures revealed that seamounts under current protection had summits ranging from 913 m in the Corner Rise Seamount Chain, to 3 756 m in the Newfoundland Seamount Chain. With this revision all summits within that maximum depth range have been identified and two others that reached 3 881 m summit in the Corner Rise Seamounts included. Collectively these revised boundaries protect all known seamounts in the NAFO Convention Area ABNJ with peaks < 4 000 m. New publications from seamounts and Orphan Knoll, released since our review in 2019 (NAFO 2020) that we have summarized above, provide additional evidence of extensive VME habitats within this depth range.

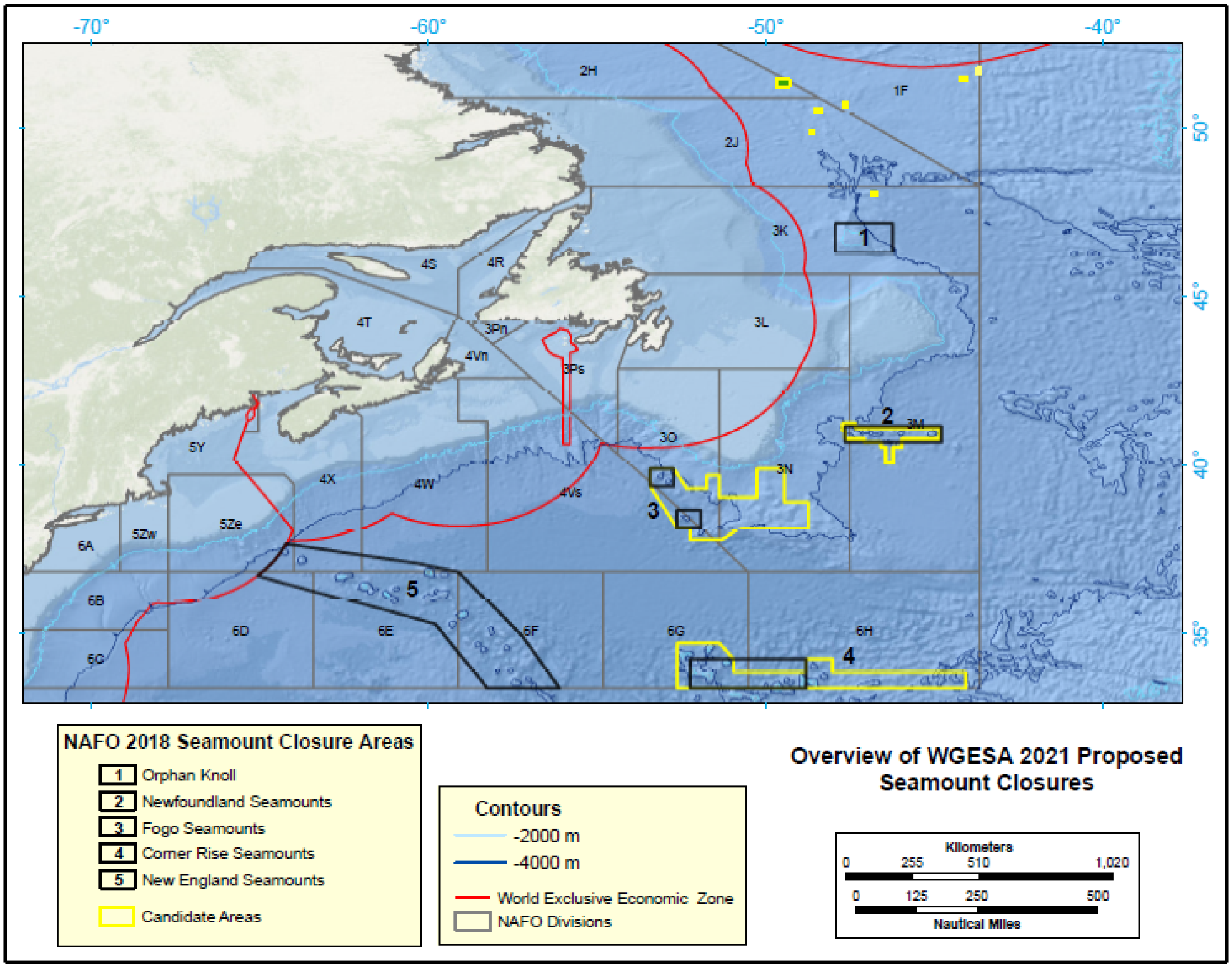

Figure 7.117. Location of the seamount areas in the NRA with current closures indicated in black outline (NAFO 2021). Proposed changes and new closures are indicated by yellow line.

vi) Summary of Management Proposals

Division 3O Coral Closure and Area 1 Tail of the Bank

<u>Area 1 – Tail of the Grand Bank Large-sized Sponge Closure</u>

- Southward extension of the Area Closure 1 (Area 1a) – Large-sized Sponges
- Establishment of two new closures (Areas 17 & 18) – Boltenia
- Establishment of a new closure (Area 16) – Bryozoans

<u>Southwestern Tail of Grand Bank</u>

- Creation of a new closure to the east of the 3O closure in the NRA to protect important concentrations of Small Gorgonian Coral, Sea Pens and Large Gorgonian Cora (Area 15a)

Area 2 Flemish Pass/Eastern Canyon and Areas 3, 13 Beothuk Knoll

<u>Area 2 Large-sized Sponge Closure</u>

- Closure of the "notch" on the northwestern side of the Area 2 to better protect Large Gorgonian Cora (Area 2a)
- Northward extension of Area 2 to protect significant concentrations of Sea Pens and Black Coral (Area 2b)

Area 3 and 13 Large-sized Sponge and Large Gorgonian Coral Closures

- No changes to Area 3 and Area 13 closures are necessary at this time

Areas 4-12 Flemish Cap and Sackville Spur Including Area 14

Eastern Flemish Cap Area 4 & 5 Large-sized Sponge and Large Gorgonian Coral Closures

- Extension of closures between Areas closures 4 & 5 (Area 4a) be implemented

Northwestern Flemish Cap Area 6 to 12 Closures

- Eastward extension of Area Closure 7 to provide greater protection for Sea Pens and Black Corals (Area 7a)
- Extension to Area Closures 8 and 9 (linking with Area Closures 8, 9 and 12) to provide a more continuous Closure to protect Sea Pens and Black Coral (Areas 8a and 9a) and improve connectivity
- Westward extension to Area Closure 10 to provide combined protection for Sea Pens and Large-sized Sponge (Area 10a)
- Northeastward extension of Area Closure 11 to provide enhanced protection for Sea Pens (Area 11a)

Area 14 Sea Pen Closure

- Re-establishment of a modified Area 14 (Areas 14a and 14b) over areas of high Sea Pen concentrations

Seamount Closures

Fogo Seamounts

- To complete the protection of seamounts on the Fogo Seamount Chain WG-ESA proposes boundary changes to the current closures to protect the seamounts shallower than 4 000 m depth

Newfoundland Seamounts

- WG-ESA proposes boundary revisions that to ensure inclusion of 15 seamounts in the Newfoundland Seamount Chain with peak depths ranging between 2 446 and 3 756 m

Corner Rise Seamounts

- WG-ESA counsels that the boundary proposed in the Corner Rise Seamount area (NAFO 2020) be extended to the east to include the 7 seamounts ranging in peak depth from 2 747-3 881 m

Seamounts Outside of Existing and Proposed Closures

- WG-ESA proposes the implementation of seven seamount closures in the NAFO Convention Area in ABNJ north of Orphan Knoll

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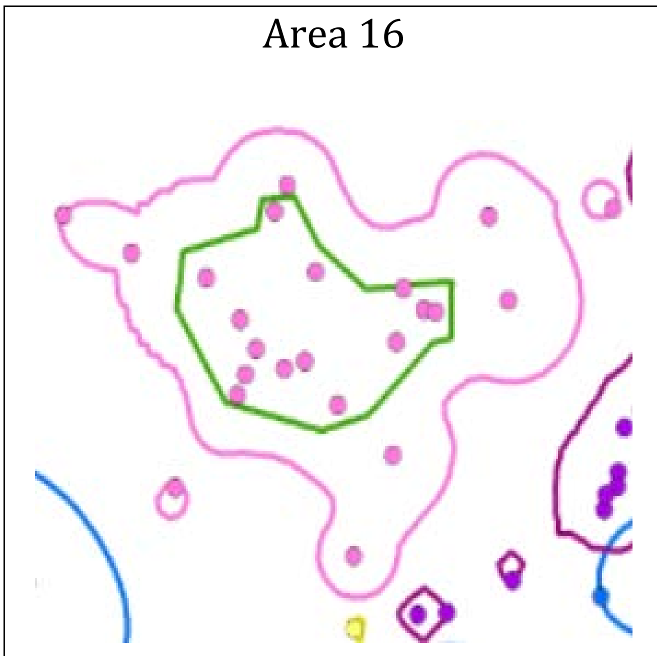
vii) Appendix

Latitude	Longitude
43.08257 N	51.34857 W
43.07500 N	51.30799 W
43.10609 N	51.22945 W
43.10403 N	51.17983 W
42.87897 N	51.15700 W
42.86778 N	51.52889 W
43.18927 N	51.79235 W
43.40361 N	51.97000 W
43.42934 N	51.83784 W
43.36821 N	51.73464 W
43.29003 N	51.61594 W
43.27069 N	51.53741 W
43.23694 N	51.46538 W
43.08257 N	51.34857 W

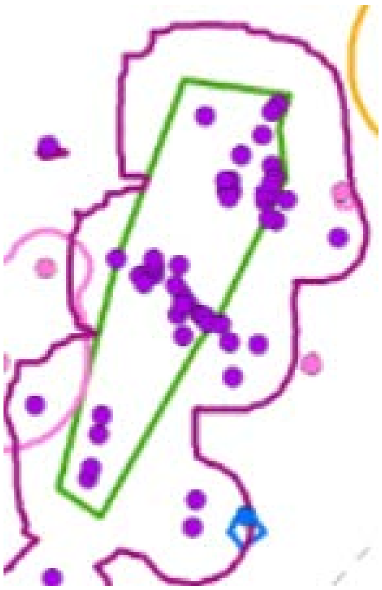
Figure 7.118 Decimal coordinates for proposed Area closure 15a. Area labels as in Figure 7.97.



Latitude	Longitude
43.16494 N	50.55787 W
43.23062 N	50.55408 W
43.26304 N	50.42504 W
43.29544 N	50.41978 W
43.30229 N	50.36430 W
43.24879 N	50.31657 W
43.20279 N	50.22954 W
43.21674 N	50.10497 W
43.14914 N	50.10001 W
43.06057 N	50.21448 W
43.04049 N	50.29363 W
43.06389 N	50.46425 W
43.16494 N	50.55787 W

Figure 7.119 Decimal coordinates for proposed Area closure 16. Area labels as in Figure 7.97.

Area 17



Latitude	Longitude
43.54086 N	49.40267 W
43.79167 N	49.33333 W
43.98800 N	49.24760 W
43.97838 N	49.08808 W
43.94285 N	49.10246 W
43.88806 N	49.08831 W
43.73380 N	49.17938 W
43.70567 N	49.20598 W
43.51276 N	49.33884 W
43.54086 N	49.40267 W

Figure 7.120 Decimal coordinates for proposed Area closure 17. Area labels as in Figure 7.97.

Area 18

Latitude	Longitude
44.24110 N	49.30176 W
44.37984 N	49.32388 W
44.42318 N	49.49658 W
44.45008 N	49.47870 W
44.43734 N	49.26429 W
44.35077 N	49.18364 W
44.23285 N	49.24218 W
44.24110 N	49.30176 W

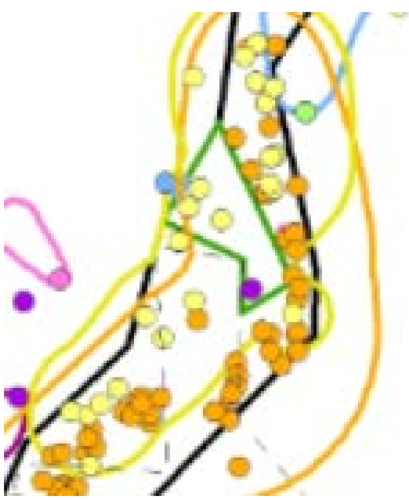
Figure 7.121 Decimal coordinates for proposed Area closure 18. Area labels as in Figure 7.97.

Area 1a

Latitude	Longitude
44.04850 N	48.88119 W
44.04828 N	48.81930 W
43.99931 N	48.82402 W
44.00031 N	48.89132 W
44.04850 N	48.88119 W

Figure 7.122. Decimal coordinates for proposed extension for Area closure 1 (Area 1a). Area labels as in Figure 7.97.

Area 2a



Latitude	Longitude
46.50617 N	47.18415 W
46.67800 N	47.05130 W
46.40669 N	46.85639 W
46.35133 N	46.98139 W
46.44222 N	46.98139 W
46.50617 N	47.18415 W

Figure 7.123 Decimal coordinates for proposed extension for Area closure 2 (Area 2a). Area labels as in Figure 7.97.

Area 2b

Latitude	Longitude
47.19639 N	46.96058 W
47.29139 N	46.58349 W
47.20159 N	46.52367 W
47.03052 N	46.60236 W
47.05808 N	46.66790 W
47.19639 N	46.96058 W

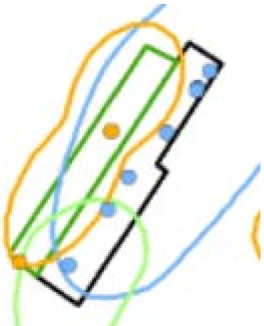
Figure 7.124 Decimal coordinates for proposed extension for Area closure 2 (Area 2b). Area labels as in Figure 7.97.

Area 11a

Latitude	Longitude
47.50040 N	46.45919 W
47.62746 N	46.27531 W
47.57767 N	46.20109 W
47.54136 N	46.27405 W
47.53611 N	46.24163 W
47.47439 N	46.26826 W
47.46008 N	46.35658 W
47.50040 N	46.35658 W
47.50040 N	46.45919 W

Figure 7.125 Decimal coordinates for proposed extension for Area closure 11 (Area 11a). Area labels as in Figure 7.97.

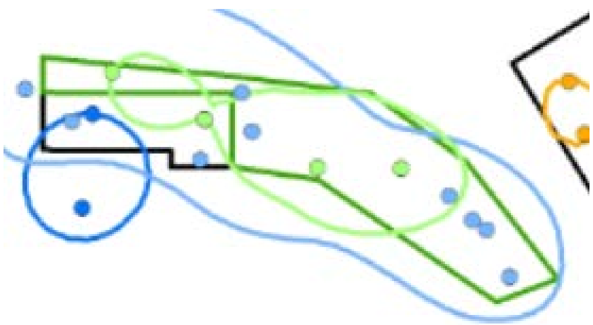
Area 10a



Latitude	Longitude
47.82819 N	46.38003 W
47.85837 N	46.43767 W
48.15374 N	46.15862 W
48.13325 N	46.09395 W
47.82819 N	46.38003 W

Figure 7.126 Decimal coordinates for proposed extension for Area closure 10 (Area 10a). Area labels as in Figure 7.97.

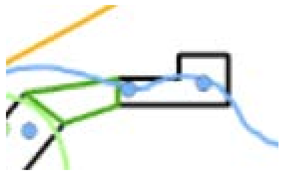
Area 7a



Latitude	Longitude
48.16916 N	44.26527 W
48.13845 N	44.38627 W
48.30190 N	44.73967 W
48.31908 N	44.91058 W
48.41728 N	44.91058 W
48.41728 N	45.28789 W
48.46450 N	45.28868 W
48.43927 N	44.90961 W
48.41587 N	44.63289 W
48.32513 N	44.44400 W
48.16916 N	44.26527 W

Figure 7.127 Decimal coordinates for proposed extension for Area closure 7 (Area 7a). Area labels as in Figure 7.97.

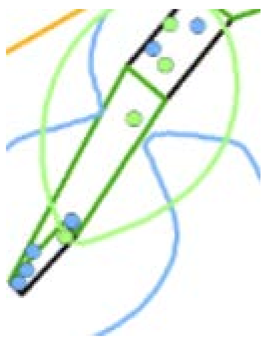
Area 8a



Latitude	Longitude
48.61528 N	45.52108 W
48.63553 N	45.32553 W
48.59900 N	45.32553 W
48.57319 N	45.43858 W
48.61528 N	45.52108 W

Figure 7.128 Decimal coordinates for proposed extension for Area closure 8 (Area 8a). Area labels as in Figure 7.97.

Area 9a



Latitude	Longitude
48.45850 N	45.57789 W
48.26863 N	45.76336 W
48.28661 N	45.79036 W
48.20183 N	45.90358 W
48.50508 N	45.66178 W
48.45850 N	45.57789 W

Figure 7.129 Decimal coordinates for proposed extension for Area closure 9 (Area 9a). Area labels as in Figure 7.97.

Area 14a

Latitude	Longitude
47.75679 N	44.05179 W
47.79843 N	44.05179 W
47.83648 N	44.05958 W
47.83635 N	43.97472 W
47.79843 N	43.98983 W
47.76533 N	43.96915 W
47.74572 N	44.04486 W
47.75679 N	44.05179 W

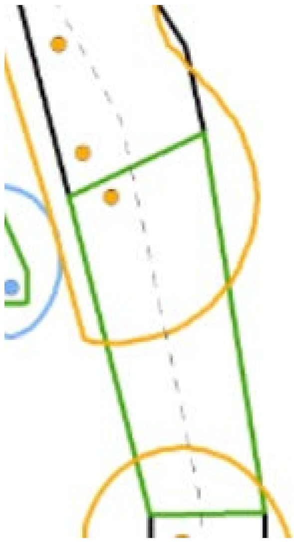
Figure 7.130 Decimal coordinates for proposed extension for Area closure 14 (Area 14a). Area labels as in Figure 7.97.

Area 14b

Latitude	Longitude
47.58938 N	43.94725 W
47.62598 N	43.88236 W
47.50133 N	43.80515 W
47.45969 N	43.80515 W
47.45969 N	43.86676 W
47.58938 N	43.94725 W

Figure 7.131 Decimal coordinates for proposed extension for Area closure 14 (Area 14b). Area labels as in Figure 7.97.

Area 4a



Latitude	Longitude
47.17500 N	43.57120 W
47.59928 N	43.71920 W
47.68178 N	43.45186 W
47.17500 N	43.34770 W
47.17500 N	43.57120 W

Figure 7.132 Decimal coordinates for proposed extension for Area closure 4 & 5 (Area 4a). Area labels as in Figure 7.97.

8. An Agent-based Modelling analysis of the impacts of fishing on sea pens in the Newfoundland-Labrador and Flemish Cap bioregions

ToR 2.2 Update on recent and relevant research related to status, functioning and dynamics of ecosystems in the NAFO area, i) Connectivity of VMEs

The evaluation of the impacts of fishing on VMEs, and the role of fisheries closures to prevent and/or mitigate these impacts is an integral part of the assessment of Significant Adverse Impacts (SAIs) on these habitats. Given the limited historical information on VMEs together with their long history of exposure to fisheries, their life history characteristics (*e.g.* slow grow), and complex population dynamics (*e.g.* sink and source spatial dynamics), the estimation of baselines (*i.e.*, pre-fisheries perturbation population levels), and the effectiveness of the closures established to protect these habitats requires integrating our current knowledge into models that can approximate their dynamics at the appropriate spatial and temporal scales.

Since 2017 WG-ESA has been developing an Agent-based Model (ABM) for sea pens in the Newfoundland-Labrador (NL) and Flemish Cap (FC) bioregions. The sea pen ABM simulates the spatio-temporal dynamics of a generalized sea pen species within the domain defined by the NL and FC bioregions, and allows exploring time scales for colonization, responses to perturbations, and the effectiveness of closures as a mechanism to promote recovery (NAFO, 2017; NAFO, 2018; NAFO, 2019).

The ABM architecture generates sea pen dynamics by tracking the actions and interactions of autonomous agents within a system, while providing a view of the system as a whole. In this model, agents represent collectives of sea pens which follow specific rules associated with life-history processes at each time step (Figure 8.1). These agents operate within a spatially-explicit matrix where each cell has properties that affect the behavioral responses of the agents. The processes/behaviors affecting and effected by the agents have probabilistic components which randomize the dynamics of the system (NAFO, 2017; NAFO, 2018; NAFO, 2019).

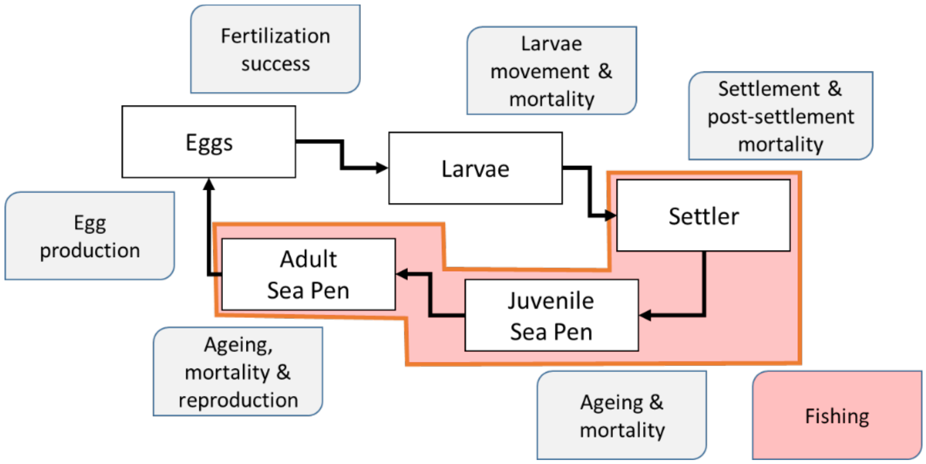


Figure 8.1. Schematic description of the life history stages/processes incorporated in the sea pen ABM. The red background indicates the life history stages impacted by fishing.

Earlier results from this model (NAFO, 2018; NAFO, 2019) indicated important connectivity within the model domain, but with clear spatial patterns and variability in magnitude depending on the local conditions. Self-recruitment within an area was found an important source of local growth, but overall growth and recovery from depletion also depends on connectivity among areas.

The initial results from the implementation of realistic fishing patterns indicated that the current system of closures (NAFO + Canada) only provides a very limited recovery capacity at the population scale, but closures can be locally effective. Closure size and location are key determinants of closure effectiveness; many NAFO sea pen closures are likely too small to be effective (NAFO, 2019).

Overall, model results have indicated that sea pen population level could have been reduced by 50% due to historical fishing. VMEs identified today represent the remnants from a much larger original population, and given the magnitude of the likely reduction, ecological processes related to these habitats could be already compromised. Fishing also has the capacity of limiting recovery within closures by impacting connectivity between VME patches, but this type of effect is local in nature (NAFO, 2019).

Recovery times within closures depends on local conditions, and the level to which the area has been depleted. For the NAFO closures, the average recovery time under current fishing condition could exceed 100 years, but individual closures can recover in up to 15-25 years. In the absence of fishing, recovery time within NAFO closures was found to be, on average, 50 years (NAFO, 2019).

While the sea pen ABM was found to reasonably capture the spatio-temporal dynamics of a generalized sea pen, and provided a useful platform for evaluating fishing impacts and the performance of current closures in a strategic sense, its representation of the sea pen distribution in some shallow areas needed improvement. This shortcoming was associated to the underlying model layers that inform the behavior of the agents (*i.e.*, bottom speeds, bearing, settlement probability). These issues were explored and addressed during the 2020 WG-ESA meeting, together with minor revisions of some model behaviors, and the update of the fishing-related layers.

Improvements in movement and settlement layers

The sea pen ABM simulates the movement of agents using two key layers, the spring-summer average bottom current velocity in each cell within the model domain, and the dominant bearing within those cells. The bottom current velocity is used to inform the randomized process that defines the fraction of larvae moved from a given cell, while the dominant bearing informs the randomized process that defines to which neighboring cell the larvae are moved into (NAFO, 2018).

In the original model formulation the bottom velocity and bearing layers were derived from average and mode (respectively) over April–August 2000-2015 from GLORYS 2V4 output (NAFO, 2018). While these layers provide a good representation of these variables at the overall scale of the model domain, some of the model shortcomings in predicting sea pen aggregations in shallow waters, as well as the generation of areas with low larval transport were associated to limitations in the local resolution of the GLORYS 2V4 output. Therefore, these layers (Figure 8.2) were updated using the 1980-2017 April-August mean values from a higher resolution circulation model for the model domain (Han *et al.*, 2021; Ma *et al.*, 2016).

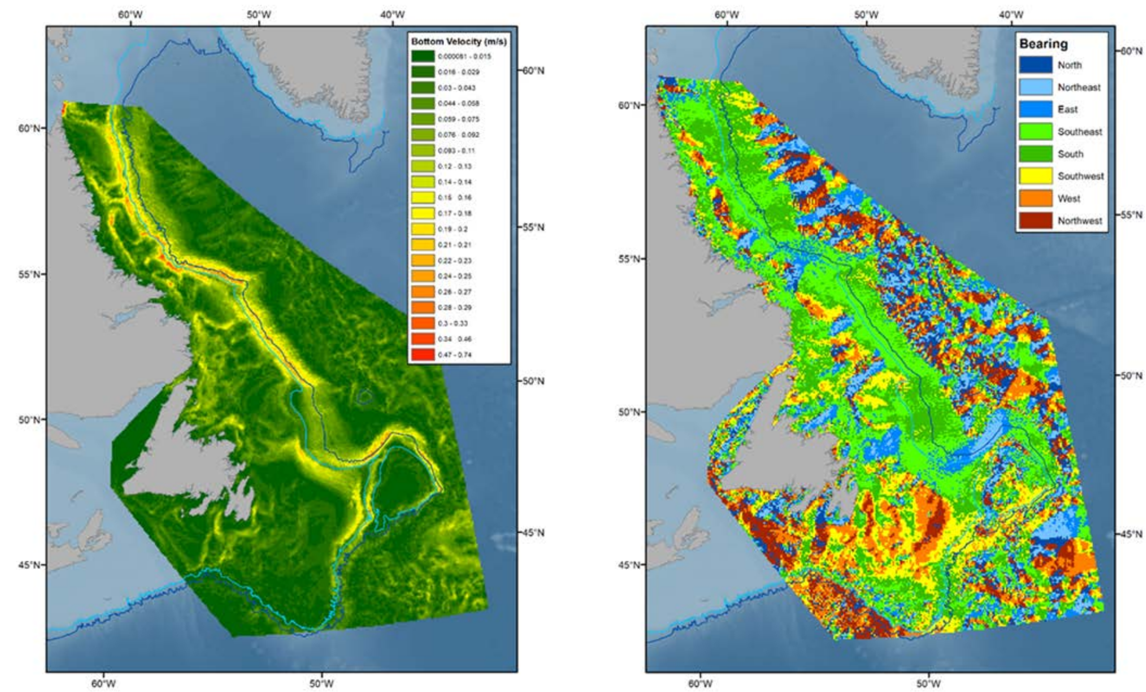


Figure 8.2. Average bottom current velocity (m/s) (left) and discretized bearing (right) used in the sea pen ABM, and derived from the 1980-2017 April-August output from a circulation model for the study area (Han *et al.*, 2021; Ma *et al.*, 2016).

An updated settlement layer (Figure 8.3) was also constructed using the new bottom current velocity and bearing information, as well as the most up-to-date data on sea pen observations (2005-2019). This settlement layer corresponds to a surface of predicted sea pen presence probability created over the study area using a Bayesian Generalized Linear Model (INLA model, R-INLA package, http://www.r-inla.org). The initial full model considers the following covariates: mean grain size of sediments (mm), overall current velocity in eastward and northward directions (m s-1), depth (m), depth^2, slope (degrees), topographic roughness, latitude, longitude, eastness, northness, and the following interaction terms: latitude:longitude, northward:eastward velocity, but the final model only retained grain size, depth, and depth^2 after a stepwise model selection process. The sea pen data used for this analysis was filtered to control for the effect of fishing (only observations from cells with less than 0.5 hours of fishing effort per km^2 per year were considered).

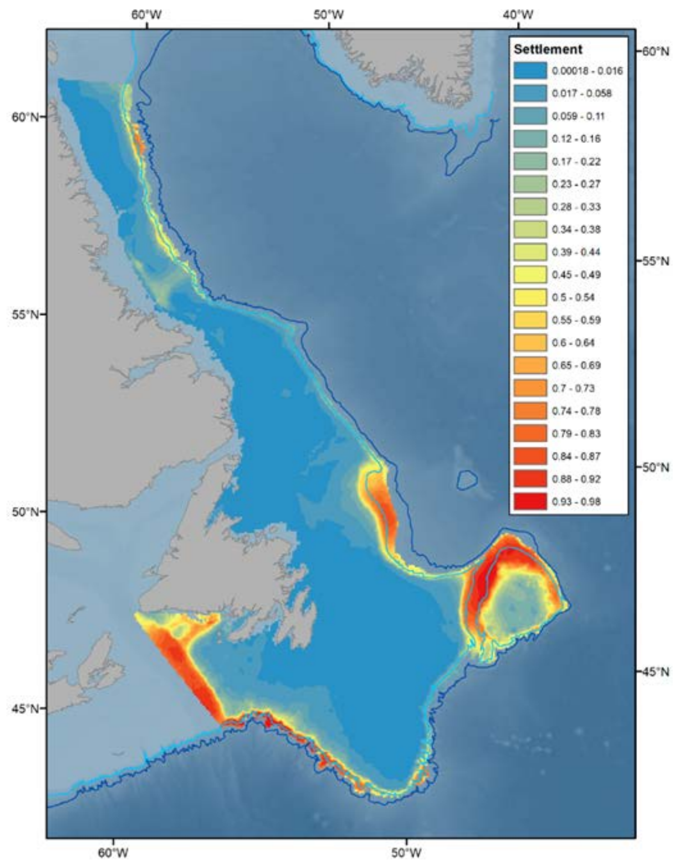


Figure 8.3. Updated settlement probability layer estimated from 2005-2019 sea pen data, and generated using a Bayesian GLM (INLA model).

Update on fishing-related layers

The simulation of fishing within the sea pen ABM follows a two-step process, the first step randomly defines if a given cell would be subject to fishing or not, while the second step defines the fishing intensity to be applied in the cell. The impact of fishing on sea pens (*i.e.*, mortality) is modelled as a function of the level of fishing effort in the cell (NAFO, 2019).

Both the probability of fishing and the fishing intensity are derived from actual fishing effort information. Vessel Monitoring System (VMS) data within the model domain for the 2008-2014 period from Canada and NAFO for all bottom-contacting fisheries were merged and filtered by speed to characterize the average fishing effort in each cell. The number of years that a cell was actually fished between 2008-2017 was used to define the average probability of fishing a cell in a given year (Figure. 8.4).

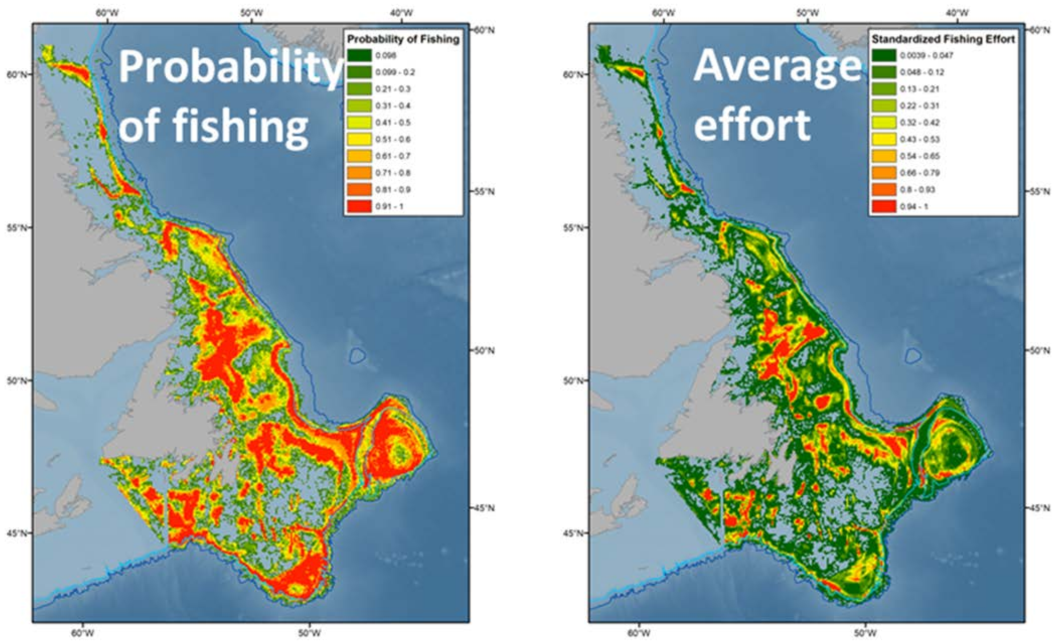


Figure 8.4. Probability of fishing (left) and average fishing effort (hours km^{-2}yr^{-1}) (right) and for all bottom-contacting fisheries derived from VMS data from the 2008-2017 period.

The approach implemented in the sea pen ABM to simulate fishing assumes that historical fishing patterns were similar to the ones observed in 2008-2017. While this assumption is unlikely to hold, especially for the period prior to the collapse of the groundfish communities in the NL bioregion, it still represents a good approximation to the fishing patterns of the last 30 years. Considering that fishing intensity prior to the collapse was higher than today, using more recent fishing patterns would render a best case scenario for historical impacts.

Implementation of fisheries closures

The evaluation of the performance of fisheries closures requires considering the fisheries closures implemented by NAFO on the NRA, and by Canada in its jurisdictional waters. In 2019, Canada implemented a series of Marine Refuges (MRs) and a new Marine Protected Area (MPA) in the NL bioregion. Most Canadian closures prohibit all bottom-contacting gears, but some only prohibit mobile gears (*e.g.,* closures numbered 4 and 5 in Figure. 8.5). Despite this difference, all analyses were done assuming that all fishing is removed when closures are implemented. This is not expected to have major impacts in the results given the low density of sea pens predicted by the model on middle-shelf areas.

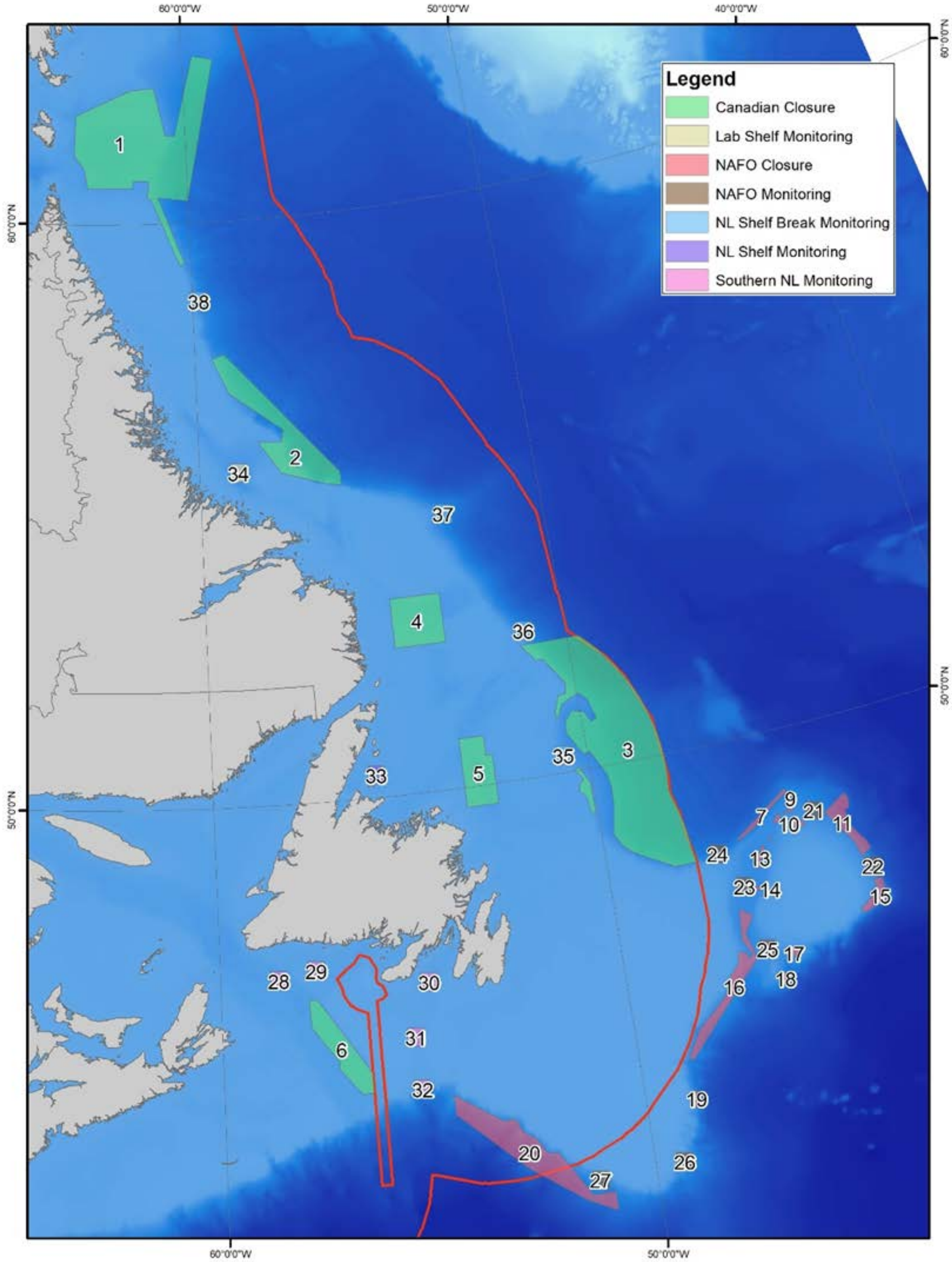


Figure 8.5. NAFO and Canada fisheries closures considered in the sea pen ABM. The numbers in this map correspond to coding conventions within the model implementation and should not be confused with the official numbering of these areas. The monitoring areas identified in this map correspond to locations where local sea pen abundance was tracked within the model to assess sea pen response to perturbations; these areas were never closed to fishing in any of the simulations performed.

Evaluation of the impacts of fishing and the effectiveness of closures

The impacts of fishing and the effectiveness of closures was evaluated by tracking the abundance of sea pens in a number of local areas within the model domain, as well as aggregates across the entire model domain. These local areas used for tracking were the closures themselves, and a series of monitoring boxes outside closures which allow examining the effect of closures in promoting sea pen recovery in nearby areas outside closures (Figure 8.6).

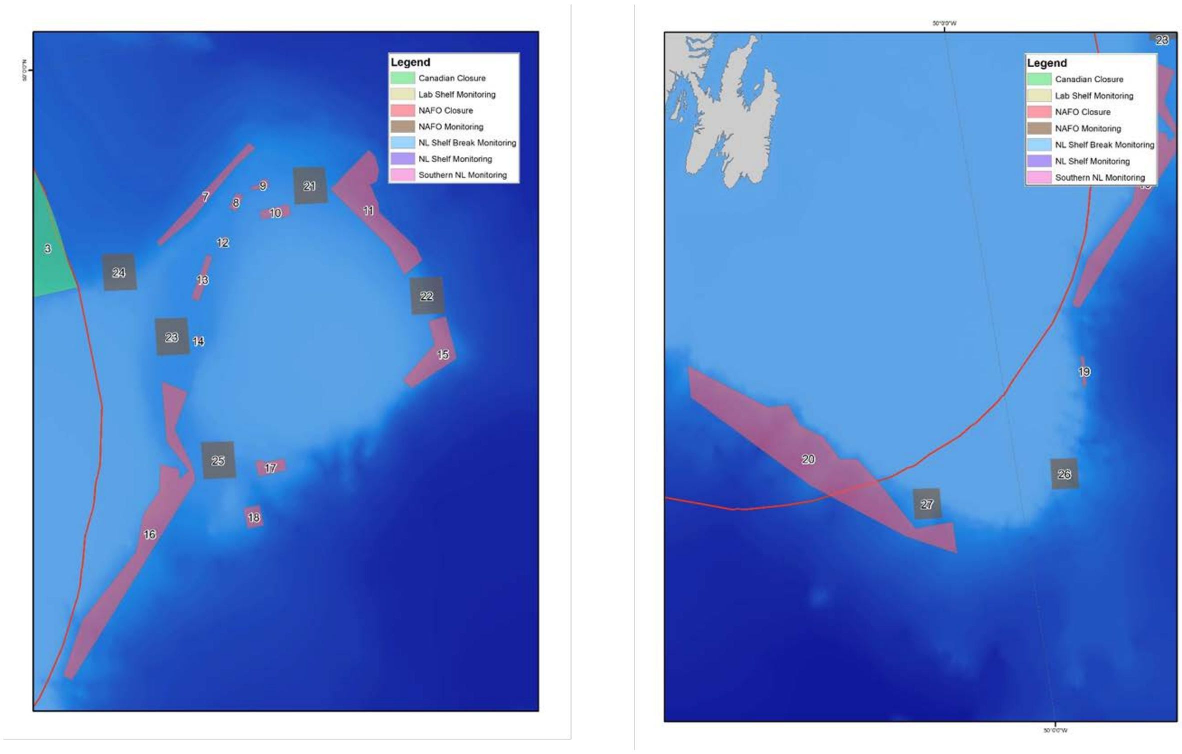


Figure 8.6. NAFO VME closures (pink) and monitoring boxes (grey) in the NRA as implemented in the sea pen ABM. The numbering of these closures and monitoring boxes indicates the id reference of these areas within the model code; they do not necessarily match the official number of the NAFO closures.

The assessment of fishing impacts on sea pens, and the performance of closures was done on the basis of a series of scenario-based model runs. All scenarios involved starting the model without fishing and with the entire domain near carrying capacity. The model was allowed to run for 100 years before applying any perturbation, and the initial 50 years of each run were considered as a burning period and discarded from the analysis. At the year 100 of each run, fishing was applied in the entire model domain and without the implementation of any closure. This unrestricted fishing was allowed to occur within the period 100-200 years of simulation. At the year 200 a specific management scenario was applied. Two scenarios were considered:

a) Closure Scenario (n=5 replicate runs): implementation of all NAFO+Canada closures, allowing fishing to continue outside the closures, and

b) No Fishing Scenario (n=6 replicate runs): complete stop of fishing in the entire model domain.

Given the random nature of each individual model run, each scenario was ran multiple times (5 times in the Closure Scenario and 6 times in the No Fishing Scenario) and the average response from these replicate runs used to characterize the response for each scenario. The average abundance prior to the initial fishing perturbation (years 79-99) was considered as pristine baseline and used to express changes in abundances as fractions of the pristine level. This also allows the comparison of performance among areas of different size.

All model runs were stopped around year 500, allowing for approximately 300 years for each scenario to play out and reach stability.

Key results

The updated model provided a better representation of sea pen distribution in shallower areas than the 2019 version (Figure 8.7).

In terms of fishing perturbations, model results indicate that a realistic representation of fishing has significant impacts in both sea pen population level and distribution (Figures 8.8, and 8.9). Total sea pen abundance drops rapidly to around 50-55% of the pristine state, and reaches a “perturbed stable state”. While the actual figure would depend on the historical patterns of fishing effort, since historical effort was higher, the current estimate is likely a best case scenario.

The bulk of the fishing impact is virtually instantaneous (Figure 8.8). Given this feature, all available field data is expected to be reflective of the “perturbed stable state”.

The current system of closures (NAFO+Canada) does not promote recovery at the total population level, but prevents fishing from expanding into remnant high density areas. Removal of all fishing allows recovery within time scales of 50-100 years, where the recovery to ~75% requires ~25-30 years (Figure 8.8).

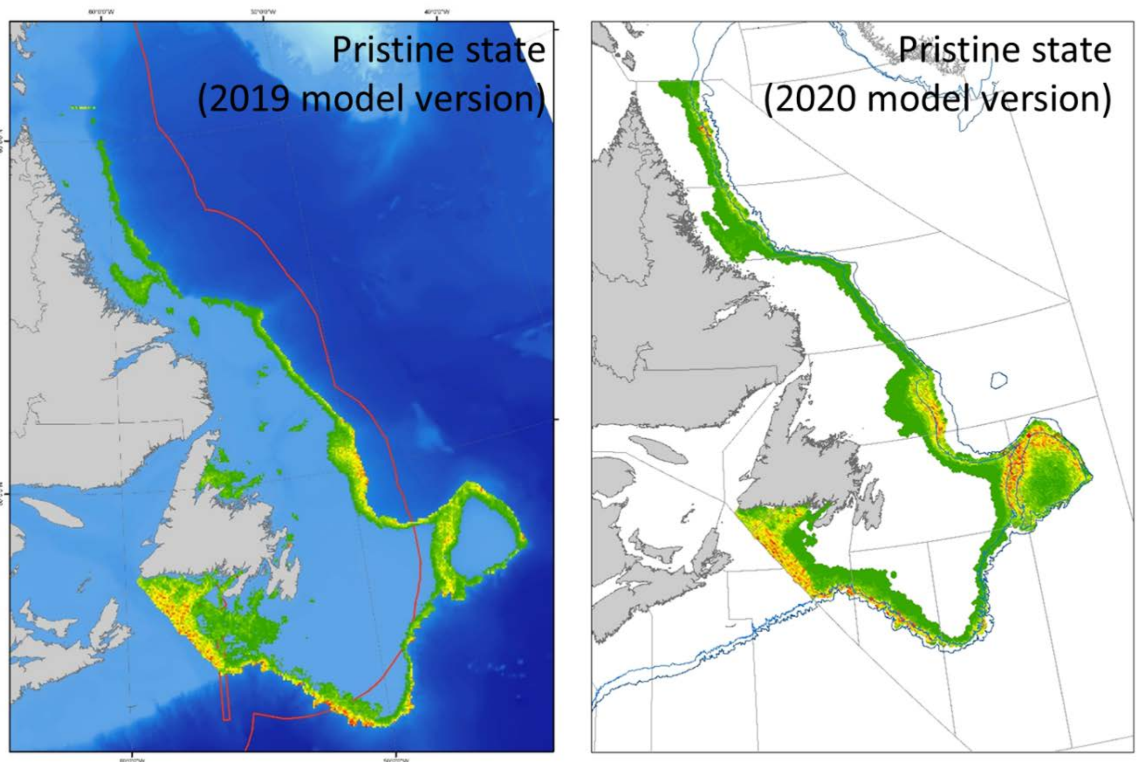


Figure 8.7. Comparison of the pristine state sea pen distribution between 2019 and the current version of the sea pen ABM. While the general distribution is similar, the current version predicts better the abundances in shallower waters (*e.g.,* the northern area of the Flemish Cap).

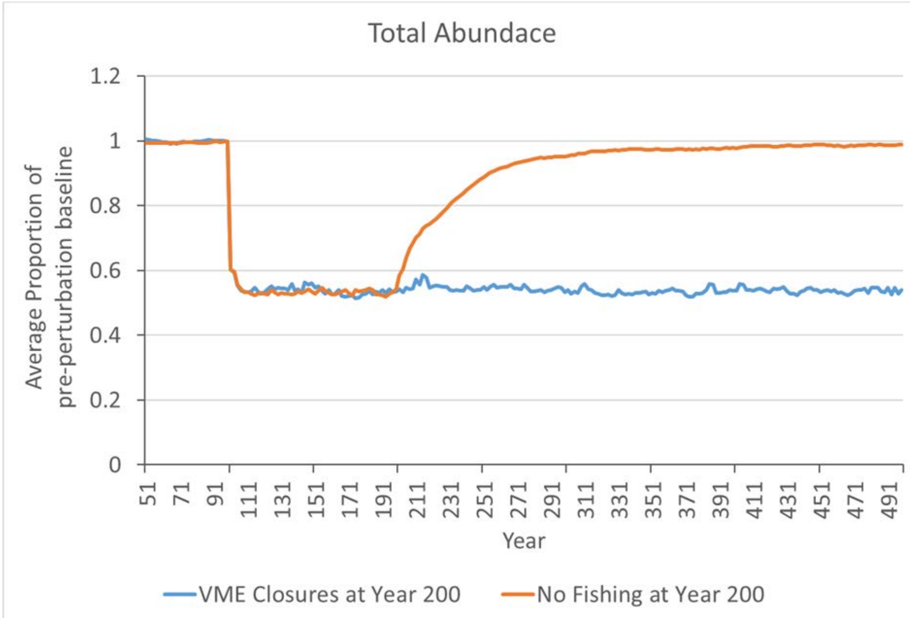


Figure 8.8. Total sea pen abundance trajectory under each one of the two scenarios considered. Implementation of current closures does not promote recovery at the population level.

The finding that the current system of closures (NAFO+Canada) does not promote recovery at the population scale is not surprising. Closures are typically established around current high concentrations, but do not displace fishing from areas where high concentrations may have existed in the past. Rebuilding of these historically important areas would be required to drive recovery at the population scale.

However, fishing increases the variability in the sea pen dynamics at the population level, and the establishment of closures appears to provide some dampening to this variability, bringing it somewhat closer to the pre-perturbation baseline variability (Figure 8.9). This is a potentially important emergent feature of the current system of closures because increased variability can exacerbate patchiness, in addition to the spatial fragmentation driven by fishing.

At the local scale, NAFO closures protect areas that have been reduced to ~60% of their pre-perturbation abundance (Figure 8.11). These closures are effective at promoting recovery within their boundaries.

Under the Fishery Closure Scenario, average recovery within closures is partial (up to ~80% of pre-perturbation), indicating that fishing outside closures impacts connectivity (Figure 8.11). Average recovery times [to the 80% level] within closures are ~30 years.

Under the No Fishing Scenario, the abundance inside the closure areas fully recovers to the pre-perturbation level. Average recovery times within closures are ~50-70 years (Figure 8.11).

The local effectiveness of individual closures is highly variable. Based on general observations of models outputs, the individual closure effectiveness depends on location and size (Figure 8.12). Location relates to connectivity and external sources of recruitment, but also to the distribution of the fishing activity that impacts that connectivity. Size relates to the ability of an individual closures to generate and retain its own recruitment.

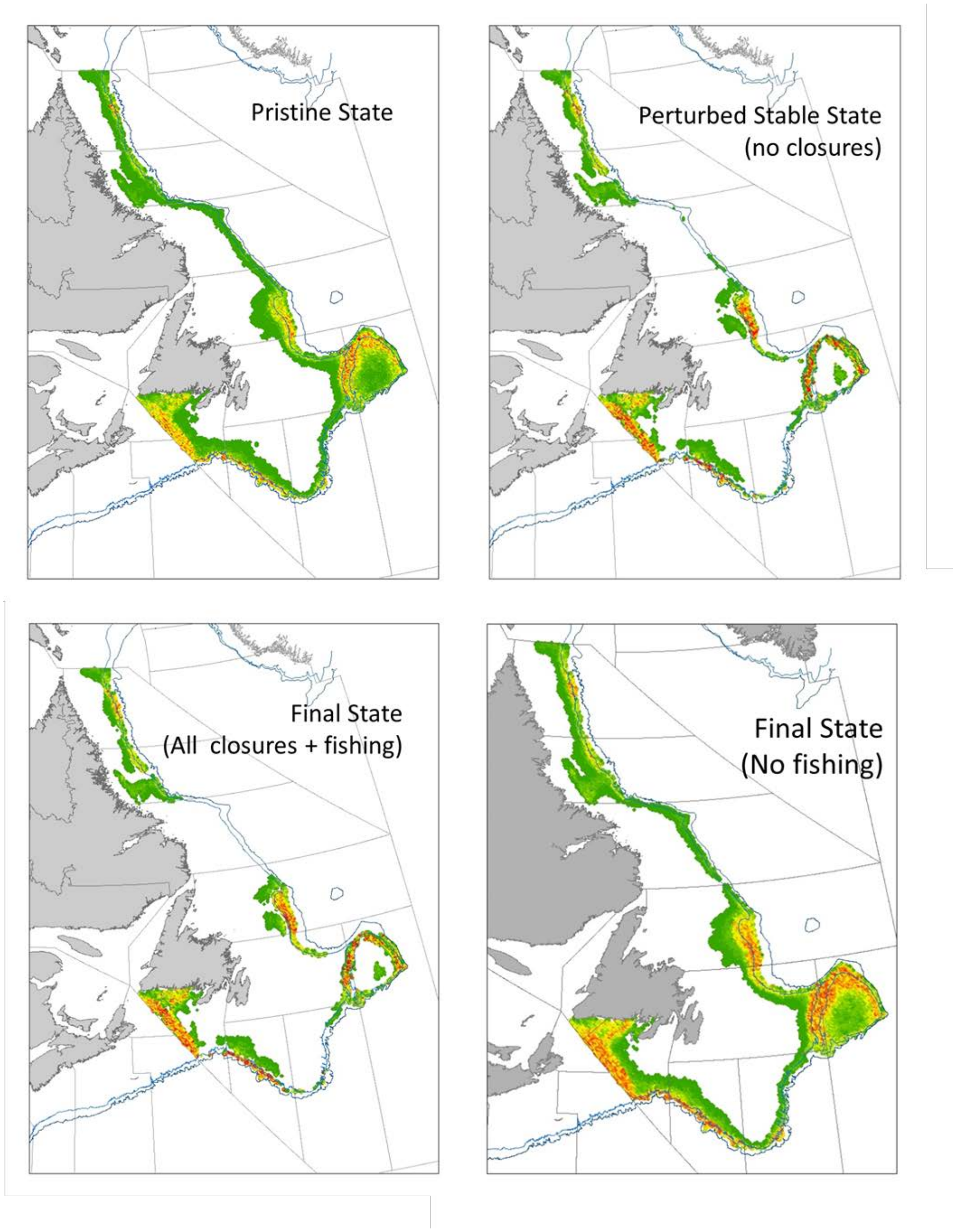


Figure 8.9. Comparison of sea pen distribution at key stages of the scenarios explored. Pristine state (top left), stable perturbed state (fishing without closures) (top right), final state with all NAFO and Canada closures implemented (Closure Scenario)(bottom left), and final state after all fishing was removed (No Fishing Scenario) (bottom right).

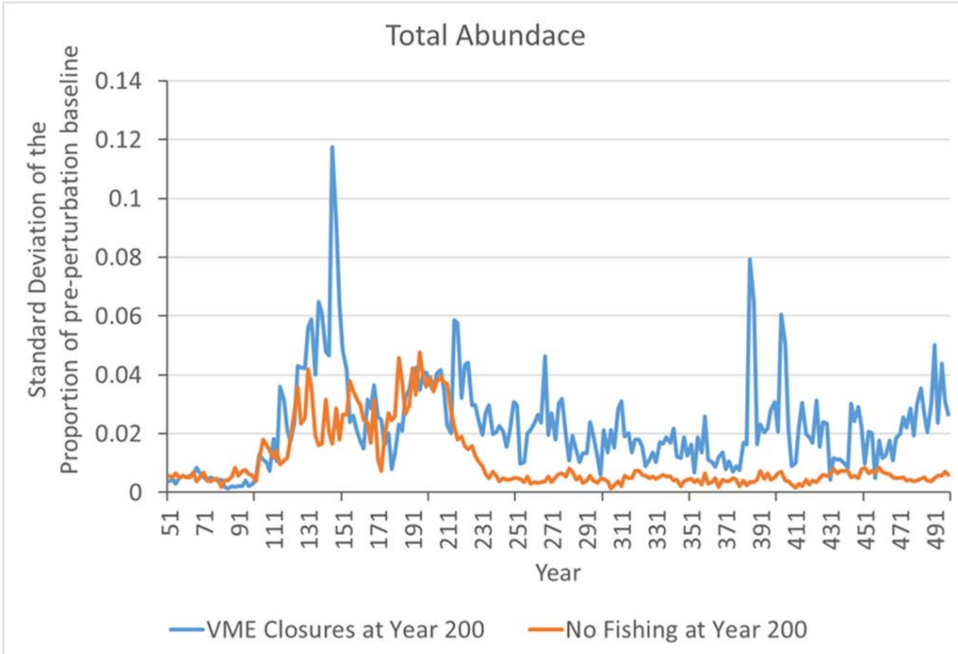


Figure 8.10. Standard deviation of the total sea pen abundance over time under each one of the two scenarios considered. Fishing increases the variability in sea pen abundance, but the implementation of closures seems to provide some dampening to this variability.

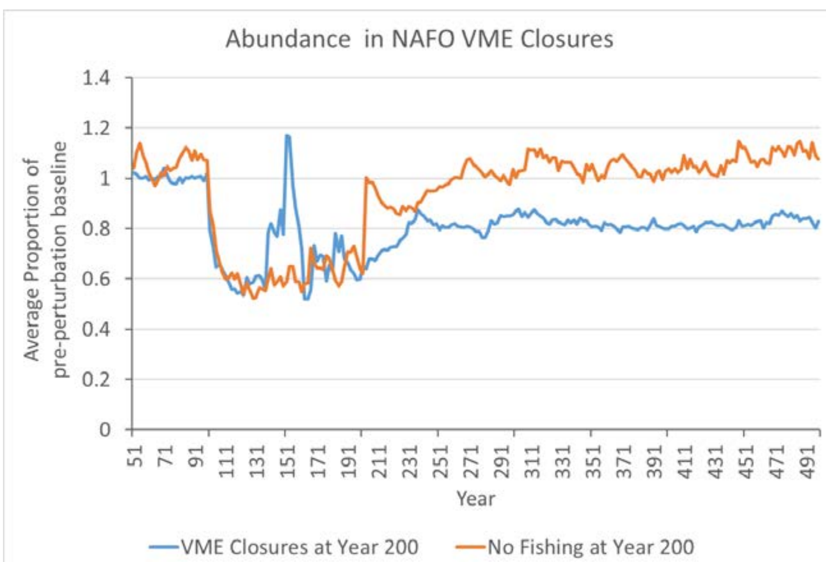


Figure 8.11. Average proportion of the pre-perturbation abundance level for all NAFO closures under the two scenarios considered. Under the Closure Scenario, the fishing activity outside the closures prevents sea pen within the closure to fully recover to pre-perturbation level.

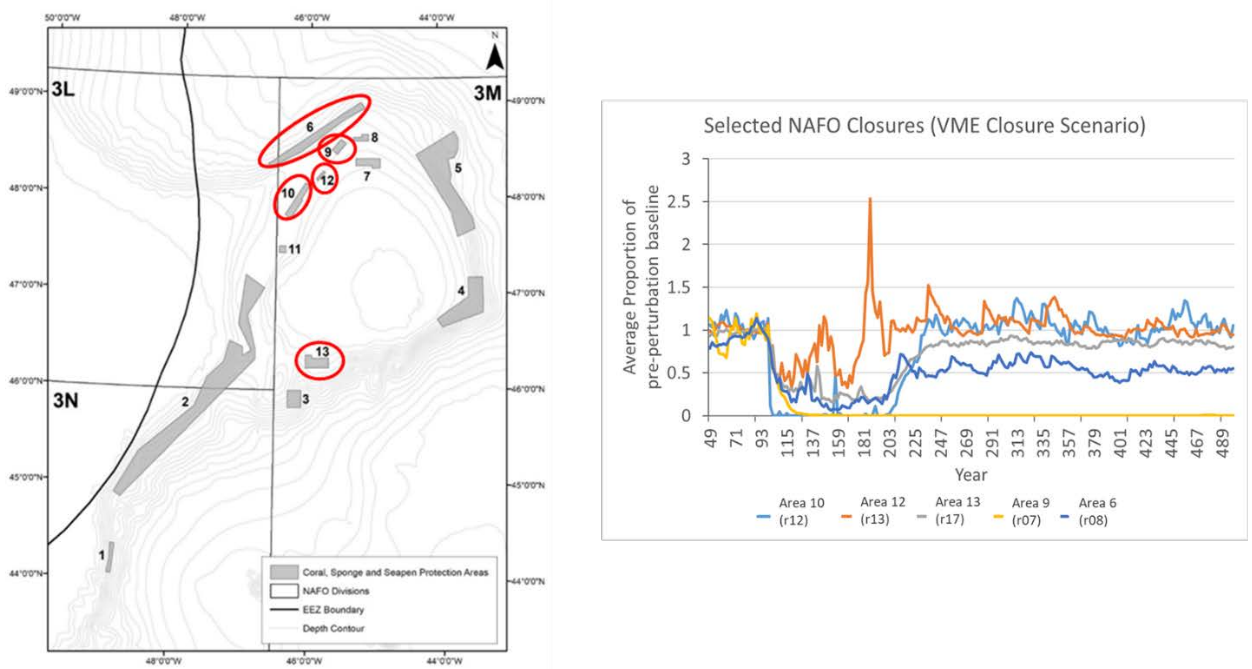


Figure 8.12. Comparison of trajectories of sea pen abundance within selected closures under the Closure Scenario. The map on the left indicates the closure areas for which the trajectories on the right are displayed; the closures on the right are labelled using the formal NAFO Area number (Area #), and the corresponding code for those areas within the sea pen ABM model (r#). The broad range of trajectories, from no recovery to full recovery, highlights the importance of location and size for determining the effectiveness of individual closures.

Conclusions

The model representation of the spatio-temporal dynamics of a generalized sea pen is credible. The model provides a useful platform for evaluating fishing impacts and the performance of current closures in a strategic sense.

A realistic representation of current fishing effort patterns indicates that fishing has had a significant effect on the sea pen distribution and abundance that we observe today. Reductions in abundance could be in the order of 45-50%, but the actual figure is dependent on the actual historical patterns of fishing effort. Since historical effort was higher, the current estimate is likely optimistic.

In addition to the reduction in population size, fishing impacts increase the variability in the population dynamics. This could exacerbate patchiness in the spatial distribution. The current system of closures (NAFO+Canada) only provides limited (if any) recovery capacity at the population scale. However, it appears to provide some dampening to the increased demographic variability that fishing generates.

Closures can be locally effective, but closure size and location are important determinants of how effective closures can be. Fishing has the capacity of impacting connectivity, and limiting recovery within closures. These effects are local in nature.

Recovery times within closures depends on local conditions, and the level to which the area has been depleted. For the NAFO closures, the average recovery time under current fishing condition would be in the order of 30 years, but average recovery level within closures only reaches 80% of the pre-perturbation level.

In the absence of fishing, recovery time within NAFO closures to the pre-perturbation level is, on average, within the 50-70 year range.

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9. Multivariate Analysis of Assemblages of fish and benthic invertebrates

ToR 2.2 Update on recent and relevant research related to status, functioning and dynamics of ecosystems in the NAFO area, f) Assess the spatial/temporal relationship between fish, invertebrates, VME indicator species and VMEs using multivariate approaches

The associations between demersal fishes and benthic habitats become of paramount importance in the development of ecosystem-based approaches to fisheries management. While the main driving force behind fish assemblages in the NAFO management area appears to be depth, studies by Kenchington *et al.* (2013) and Devine *et al.* (2020) have shown associations between certain fish species and varying densities of sponge grounds and dense corals. Both Buhl-Mortensen, *et al.* (2010) and Devine *et al.* (2020) concluded that habitat association were mainly related to structural complexity, whether provided by physical or biogenic habitat features. There is a need to gain more understanding of the links between benthic habitats, especially VMEs, and fish communities in the NRA. One way to investigate associations between fish and VME is through a multivariate analysis of full trawl catches of fish and invertebrates to identify potential overlap of communities and habitat.

Data on the biomass fish and invertebrates were obtained from survey trawls acquired during annual fishery surveys conducted by the European Union (Spain) between 2011 and 2019. The study area, delineated by the extent of the NAFO fishing footprint in 3LMN, contained 3379 survey trawls.

A community matrix with fish and invertebrate biomass was filtered to ensure each taxon included in the dataset was present in a minimum of three (3) trawl sets and each included trawl set contained a minimum of 3 taxa. The community matrix was square-root transformed, and a dummy variable with a low value (0.001) was included in each sample.

Non-metric multidimensional scaling (nMDS) was used to visualise the level of similarity in fish and invertebrate communities between the survey trawls (Figure 9.1). The nMDS was run using the ‘vegan’ package (v.2.5-6; Oksanen *et al.*, 2019) in R (v. 3.5.1; R Core Team, 2018) using Bray-Curtis dissimilarity on the square root transformed community matrix applying a double Wisconsin standardisation. The plot has a 2D stress value of 0.18. The square root transformed community matrix was clustered into groups partitioning around medoids (PAM) approach to k-means clustering (Kaufman and Rousseeuw, 1990) with the optimum number of groups determined from average silhouette width. The partitioning was done using the ‘pamk’ routine in the the ‘fpc’ package (Hennig, 2020) in R, using Bray-Curtis dissimilarity. The optimal number of groups selected by the ‘pamk’ routine based on average silhouette width was six. Figure shows the plotting of cluster groups onto the MDS ordination.

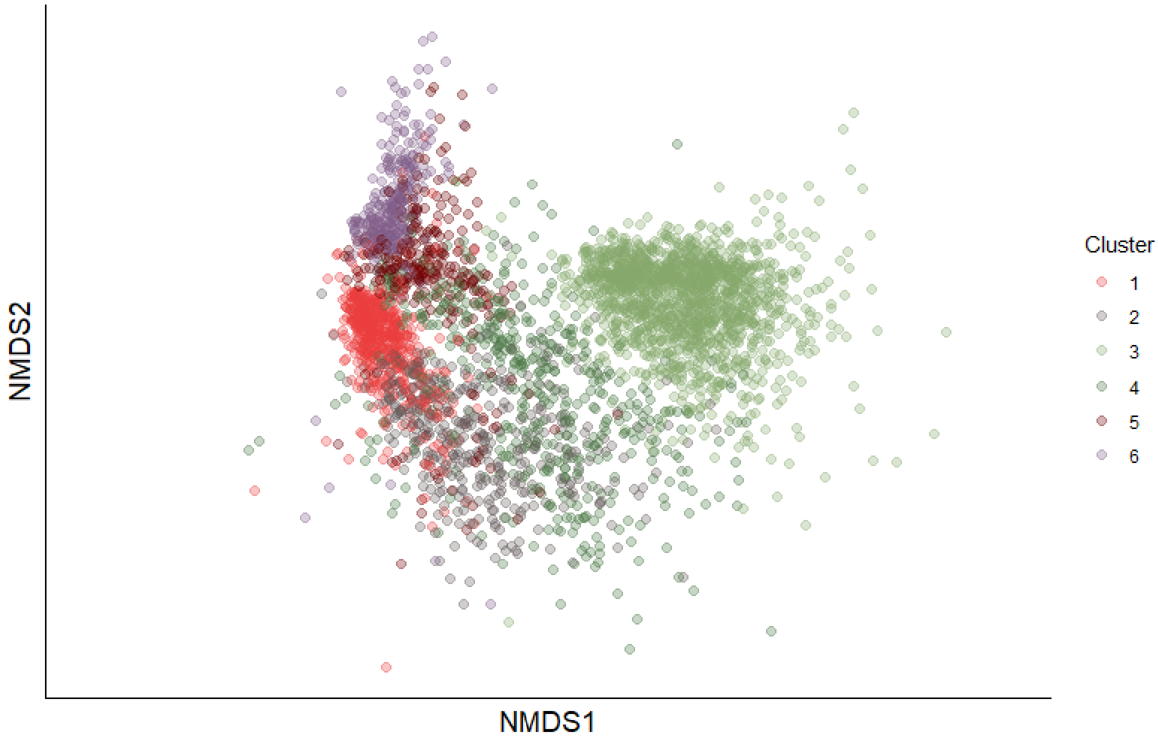

Figure 9.1 Partitioning around medoids (pamk) groups plotted on the MDS ordination using fish and invertebrate data.

Fish and benthic fauna associated with the cluster groups was investigated using Dufrêne & Legendre's Indicator Value Analysis (Dufrêne & Legendre, 1997). The analysis was done using the 'IndVal' function in the 'labdsv' package (Roberts, 2019) in R. The indicator value approach is based on the expectation that a good indicator species is on that is both more abundant and common in one group than others. In 'IndVal' there are measured by the relative frequency (the proportion of the occurrences of species *i* in class *j*) and the relative abundance or biomass (the proportion of the individuals or total biomass of species *i* that are in class *j*) of each taxon in each predetermined group. The indicator value is the product of relative frequency and relative abundance. Statistical significance of the indicator value is tested through permutation.

Significant indicator values for taxa ranged from 0.04 to 0.97. Each group had at least 3 taxa with a significant indicator value above 0.1 (Table 9.1). Cluster group3 had the most indicator taxa at 21.

Table 9.1 Indicator values for taxa by cluster group. Only significant values with an indicator value above 0.10 are listed.

Cluster	Taxon	Ind. Val.	Probability
1	*Gadus morhua*	0.49	0.001
	Sebastes norvegicus	0.45	0.001
	Glyptocephalus cynoglossus	0.37	0.001
2	*Sebastes mentella*	0.91	0.001
	Sebastes fasciatus	0.79	0.001
	Pandalus	0.33	0.001
	Anarhichas denticulatus	0.18	0.001
	Anarhichas minor	0.11	0.001
3	*Antimora rostrata*	0.95	0.001
	Coryphaenoides	0.92	0.001

	Synaphobranchus	0.85	0.001
	Centroscyllium fabricii	0.66	0.001
	Reinhardtius hippoglossoides	0.65	0.001
	Nezumia	0.60	0.001
	Macrourus berglax	0.59	0.001
	Anthoptilum	0.39	0.001
	Porifera	0.26	0.001
	Alcyonacea	0.26	0.001
	Euphausiidae	0.23	0.001
	Heteropolypus	0.21	0.001
	Halipteris finmarchica	0.17	0.001
	Nephtheidae	0.16	0.001
	Flabellum	0.16	0.001
	Chaetognatha	0.15	0.001
	Pennatula	0.14	0.001
	Acanella	0.14	0.001
	Cephalopoda	0.12	0.001
	Geodiidae	0.11	0.001
	Aristeidae	0.11	0.001
4	*Sebastes*	0.78	0.001
	Actiniaria	0.38	0.001
	Merluccius bilinearis	0.25	0.001
	Polymastiidae	0.20	0.001
	Sabellidae	0.18	0.001
	Brachiopoda	0.13	0.001
	Ascidiacea	0.13	0.001
	Pycnogonida	0.11	0.001
5	*Mallotus villosus*	0.58	0.001
	Hippoglossoides platessoides	0.45	0.001
	Echinoidea	0.42	0.001
	Amblyraja radiata	0.35	0.001
	Lycodes	0.30	0.001
	Ophiuroidea	0.23	0.001
	Bryozoa	0.17	0.001
	Hexanauplia	0.16	0.001
	Bivalvia	0.16	0.001
	Anarhichas lupus	0.15	0.001
6	*Limanda ferruginea*	0.97	0.001
	Holothuroidea	0.60	0.001
	Ammodytes dubius	0.49	0.001
	Hydrozoa	0.27	0.001

Group 1 was characterised by cod (*Gadus morhua*), the redfish *Sebastes norvegicus* and Witch (*Glyptocephalus cynoglossus*).

Group 2 was represented largely by the other two redfish *Sebastes mentella* and *Sebastes fasciatus*, and to a lesser extent *Pandalus* sp. shrimp and wolffish (*Anarhichas denticulatus* and *Anarhichas minor*). No benthic invertebrate fauna were included in the group.

Group 3 is the largest group and includes the widest variety of both fish and invertebrate taxa. The blue antimora (*Antimora rostrata*) and ratTails (*Coryphaenoides* spp.) have the strongest association with this group, but it also includes the Greenland halibut (*Reinhardtius hippoglossoides*). This group includes most of the VME indicator taxa, including sponges, sea pens and gorgonians, although the association is not consistent as implied by the lower indicator values. The strongest association by VME taxa is shown by *Anthoptilum* sp. sea pens (0.39). A closer look at the relative frequency and abundance of these taxa in Group 3, however, shows that the lower indicator values are mainly due to low prevalence of the taxa in general (Table .1). *Geodia* spp. sponges, for example, are only present in 11% of the scientific trawls included in Group 3, but those trawls represent 99% of all *Geodia* spp. biomass. *Geodia* spp. are therefore almost exclusive to group 3 but are not consistently present. A similar, pattern is found for black corals, *Isidid alcyonaceans*, including *Acanella* sp., tetillid sponges, asprophorid sponges and all sea pens. *Asconema* sp. sponges occur across Groups 3 and 4. At the generic taxonomic levels of identification sponges and Alcyonacea occur across all groups (Table 9.2).

Table 9.2. Breakdown of the relative frequency and relative abundance values making up the indicator value for VME indicator taxa.

	Rel.Freq.						**Rel.Ab.**					
	1	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
Antipatharia	0.00	0.06	0.09	0.00	0.00	0.00	0.00	0.14	0.85	0.01	0.00	0.00
Acanella	0.00	0.08	0.19	0.04	0.00	0.00	0.01	0.17	0.72	0.08	0.02	0.00
Anthoptilum	0.02	0.21	0.50	0.06	0.01	0.00	0.03	0.14	0.78	0.05	0.00	0.00
Ascidiacea	0.16	0.34	0.33	0.59	0.44	0.26	0.04	0.07	0.16	0.22	0.26	0.26
Asconema	0.00	0.00	0.14	0.15	0.01	0.00	0.00	0.00	0.62	0.37	0.00	0.00
Astrophorina	0.01	0.01	0.10	0.01	0.00	0.00	0.03	0.01	0.96	0.00	0.00	0.00
Bryozoa	0.06	0.05	0.07	0.21	0.48	0.34	0.03	0.01	0.04	0.07	0.36	0.49
Flabellum	0.00	0.16	0.21	0.01	0.00	0.00	0.00	0.21	0.73	0.05	0.00	0.00
Geodiidae	0.01	0.01	0.11	0.00	0.00	0.00	0.00	0.01	0.99	0.00	0.00	0.00
Halipteris finmarchica	0.03	0.09	0.24	0.04	0.00	0.00	0.08	0.15	0.73	0.04	0.00	0.00
Pennatula	0.02	0.07	0.19	0.05	0.00	0.00	0.04	0.10	0.75	0.09	0.02	0.00
Polymastiidae	0.29	0.25	0.16	0.47	0.05	0.00	0.21	0.14	0.17	0.43	0.04	0.00
Tetillidae	0.02	0.00	0.09	0.06	0.01	0.00	0.04	0.00	0.70	0.25	0.01	0.00
Isididae	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.20	0.70	0.00	0.11	0.00
Alcyonacea	0.34	0.48	0.74	0.63	0.64	0.33	0.14	0.11	0.35	0.18	0.16	0.06
Porifera	0.83	0.67	0.55	0.73	0.47	0.13	0.12	0.08	0.47	0.17	0.12	0.04

Group 4 is characterised by the redfish Sebastes, where the fish have not been identified to species. The identification at level of genus may be due to these fish being of small size. A more detailed investigation of the data is required to draw any conclusions on how these Sebastes differ from those in Groups 1 and 2. The other fish species represented in Group 4 is the silver hake *Merluccius bilinearis*. Benthic fauna in the group consists of soft bodies sessile fauna, such as anemones (Actiniaria), polymastid sponges and ascidians, along with sabellids worms and brachiopods. The strongest associations with Group 5 are for Capelin (*Mallotus villosus*), American plaice (*Hippoglossoides platessoides*) and sea urchins (Echinoidea). Other fish in the group include throrny skate (*Amblyraja radiata*) and eelpout (*Lycodes* sp.). Benthic macrofauna also include brittlestars (Ophiuroidea) and bryozoans. Group 6 has a strong association with yellowtail flounder (*Limanda ferruginea*). Sandeels (*Ammodytes dubius*) are also associated with Group 6. Benthic fauna in Group 6 is represented by holothurians and hydrozoans.

Figure 9.2 illustrates the pattern of taxa grouping together by plotting the species scores of the nMDS onto the ordination with environmental variables presented correlation vectors. Species scores are weighted averages of site scores with varying biomass of the species. The patterns reflect those seen in the taxa characterising the cluster groups.

Figure 9.2. MDS plot showing the taxon centroids and environmental vectors. Colours correspond to taxonomic groupings: **Fish, Anthozoans, Porifera, Ascidiacea and other invertebrates.**

The cluster groups are mostly structured by depth, and a split between the continental shelf edge of the Grand Banks and the Flemish Cap (Figure 9.3 and 9.4). Temperatures and topographic exposure are linked to depth and follow the same pattern between groups. Group 3, which includes the VME indicator taxa is the most distinct from others, covering waters deeper than ~800 m. Groups 1 and 2, which include cod and the three redfish species mainly occur on top of the Flemish cap in distinct depth bands. Although some occurrences of

Group 1 are seen on the edge of the Grand Bank. Group 4, characterised by Sebastes, silver hake and soft-bodied benthic macrofauna, such as sea anemones, polymastid sponges and ascidians occurs in the same depth band as Group 2 but is mainly seen on the Grand Bank side of the Flemish Pass, with scattered occurrences on the Flemish cap. Groups 5 (including Capelin, American Plaice and sea urchins) and 6 (with Yellowtail flounder, sandeels, holothurians and bryozoans) are located on top of the grand bank in two depth bands above 300 m and 100 m, respectively. They see much lower minimum temperatures than the other groups and the largest annual temperature ranges (Figure 9.). Group 6 encounters the lowest oxygen conditions.

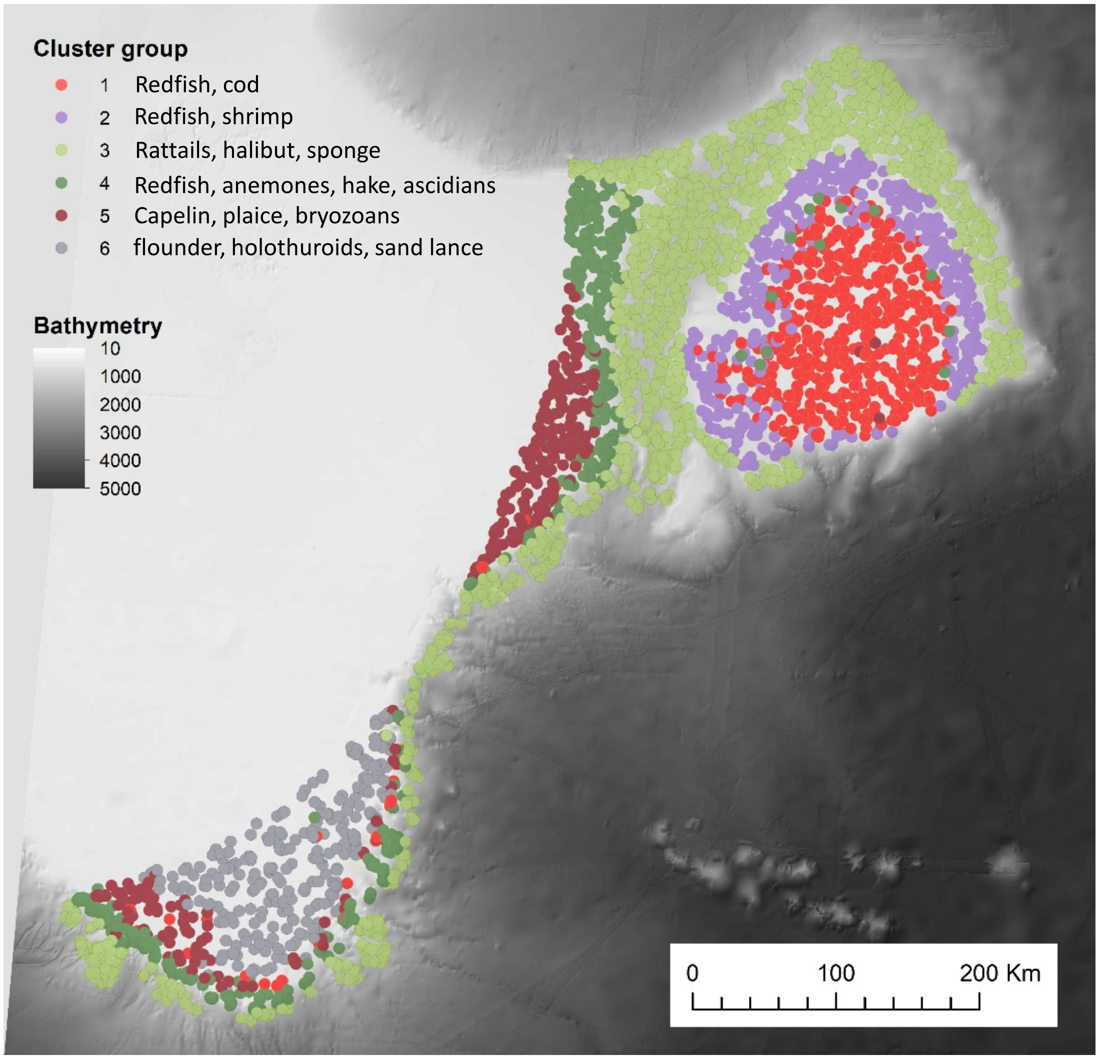

Figure 9.3. NAFO divisions overlaid onto the MDS ordination of fish and invertebrate communities.

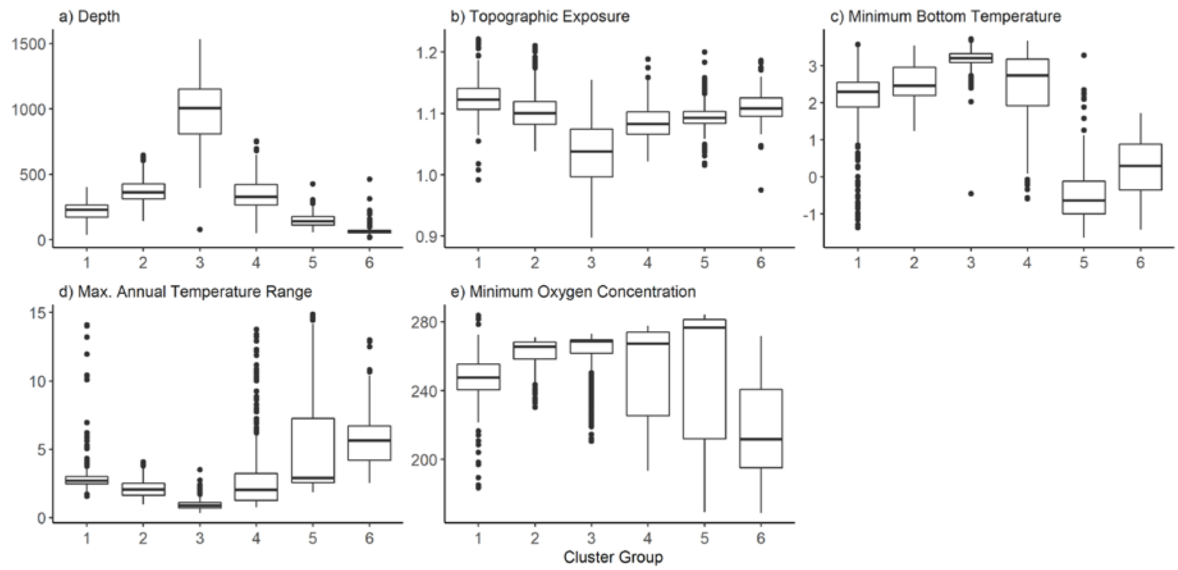

Figure 9.4. Ranges of environmental variables in cluster groups. a) Depth (m), b) Topographic exposure index, c) Minimum bottom temperature (^{0}C), d) Maximum annual temperature range (^{0}C) and e) Minimum oxygen concentration.

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10. Ecosystem Road Map

ToR 3.1, Commission Request 5

The Commission requests that Scientific Council continue to refine work on the Ecosystem Road Map:

i. Continue to test the reliability of the ecosystem production potential model and other related models
ii. Report on these results to WG –EAFFM and WG-RBMS to further develop how it may apply to management decisions
iii. Develop options of how ecosystem advice could inform management decisions, an issue which is directly linked to the results of the foreseen EAFM roadmap workshop.
iv. Continue its work to develop models that support implementation of Tier 2 of the EAFM Roadmap.

Not Addressed

11. Ecosystem summary Sheets

ToR 3.2, Commission Request 18

The Commission request that Scientific Council proceed with developing the ecosystem summary sheets for 3M and 3LNO and move toward undertaking a joint Workshop with ICES (International Council for the Exploration of the Sea) as part of a peer review of North Atlantic ecosystems.

Not Addressed

12. Activities other than fishing

ToR 3.3 Commission Request 16

"The Commission requests Scientific Council to continue to monitor and provide updates resulting from relevant research related to the potential impact of activities other than fishing in the Convention Area. Further, that the Secretariat and the Scientific Council work with other international organizations, such as the FAO and ICES, to bring in additional expertise to inform the Scientific Council's work".

a) Standardized protocol for collection of seabed litter data in the EU groundfish surveys

Scientific Council recommended to the NAFO Commission that standardized protocols for seabed litter data collection should be implemented by all Contracting Parties as part of their groundfish surveys, to facilitate the on-going monitoring and assessment of seabed litter in the NAFO area.

In line with such recommendation, the Spanish Institute of Oceanography (IEO) developed a protocol to be used in all the EU groundfish surveys in the NRA. The objective of the protocol is to expand the seabed litter data collection started in year 2006 (García-Alegre *et. al*, 2020) in the Flemish Pass (Div. 3L) to the other areas sampled by the EU surveys: Flemish Cap (Div. 3M) and the Grand Banks (Divs. 3NO) using a same methodology and standardized forms. This protocol was implemented in Divs. 3LNO (2018) and Div. 3M (2019) as a pilot experiment. In 2020, a common standardized protocol was ready to use in all the EU groundfish surveys in the NRA, but this year, due to COVID-19 situation, only the EU-Spain & Portugal groundfish survey (Div. 3M) was conducted. For each haul, all items collected by the bottom trawl gear were examined, counted, weighed, categorized, and recorded onboard. Moreover, the size of items was recorded and photos were taken, when possible. Table 12.1. summarizes the information on seabed litter available from EU groundfish surveys. Data from 2006-17 (Div. 3L) has previously been summarized (NAFO, 2019; García-Alegre *et. al*, 2020)[68]. Results indicate a generally low occurrence and density of seabed litter with only 8.3% of hauls having seabed litter present, however, 62% of the seabed litter sampled were identified as being associated with both NAFO managed and non-managed fishing activities.

[68] EU Funded projects ATLAS (A Transatlantic Assessment and Deep-water Ecosystem-based Spatial Management Plan for Europe) and CLEANATLANTIC (Tracking Marine Litter in the Atlantic Area)

Table 12.1. Information on seabed litter available from EU groundfish surveys.

NAFO Divs.	Data period	Source
3L	2006-2019	EU-Spain groundfish survey
3NO	2018-2019	EU-Spain groundfish survey
3M	2019-2020	EU-Spain & Portugal groundfish survey

b) Update on oil and gas activities

Information on geographical location of offshore oil and gas activities in the NAFO Convention Area (wells, licences, proposed project areas, etc.) is publicly available from several sources, including websites and project reports (*e.g.* www.cnlopb.ca; https://www.canada.ca/en/impact-assessment-agency.html; http://exploration.nalcorenergy.com/ness/overview/). In contrast, available information on the potential impacts of such activities (routine operations and accidental events) in the NRA and the corresponding mitigation measures is scarce or difficult to obtain.

Offshore oil and gas activities can have detrimental environmental effects during each of the main phases of exploration, production, and decommissioning (Cordes *et al.,* 2016), but the impact has not been assessed within the NRA. Environmental effects include impacts from routine operational activities such as drilling waste and produced water discharges (Neff *et al.*, 2011; Neff *et al.*, 2014), accidental discharges and spills (Cordes *et al.,* 2016, https://www.cnlopb.ca/incidents/ibjul182019/), long-term impacts on deep-sea corals (*e.g.*, Girard and Fisher, 2018) and impacts on deep-sea sponges and their associated habitats (Vad *et al.,* 2016).

The map in Figure 12.1 shows the updated information on oil and gas activities in NAFO Divs. 3LMN, collected from publicly available sources. In comparison with the information assessed previously reported by WG-ESA (NAFO, 2019), the updated map reveals an increase of the exploration activities within Divs. 3LMN. The map shows four additional *Wells* located in Div. 3L (one of them inside NAFO Closed Area No2 (large sponges), two additional *Significant Discovery Licences* in Div. 3M and several additional *Exploration Licences* in Divs. 3LN. Figure 1 also shows an additional *Exploration Drilling Project* that can proceed in Divs. 3LM, involving exploration drilling within two *Exploration Licences* within the Flemish Pass Basin (EL1144 and EL1150: see location in Figure 2). Moreover, the updated map reveals the overlap, and potential conflicts, between different regulatory and jurisdictional frameworks (*e.g.*, NAFO and CNLOPB[69]). Vulnerable ecosystems inside NAFO VME closures (and outside NAFO footprint) are currently protected against Significant Adverse Impacts from commercial bottom fishing, but they are unprotected regarding potential threats from activities other than fishing (*e.g.*, drilling activities inside VME closures in Divs. 3LM).

Some of the oil and gas exploration and proposed production activities in Divs. 3LMN, appear to have significant spatial overlap with NAFO fisheries and VMEs, which could result in potential conflicts between users of the marine space (*e.g.*, reduction of fishing opportunities) and between users and the environment (*e.g.*, VMEs). Particularly, this is the case of the Bay du Nord Development Project (Figures 12.1 and 12.2) located in the Flemish Pass. Figure 2 shows the details of the planned production installations (*i.e.*, templates, flowlines, FPSO vessel, anchors, and moorings), showing the location of some templates within NAFO Closed Area No 10 (sea pen) as well as future potential tie-back opportunities inside a VME polygon and close to the NAFO fishing grounds. This could result in a future expansion of the Proposed Core Development Area of the project (outlined in red in Figures 1 and 2), which is a cause for concern.

Pollution incidents are often a source of conflicts between different users of the marine space and between users and the marine ecosystems (Durán Muñoz *et al.,* 2020). Table 12.2 summarizes the updated information on recent incidents, including a transboundary oil spill, derived from offshore oil and gas activities in the NW

[69] Canada-Newfoundland and Labrador Offshore Petroleum Board

Atlantic, based on available data. During the period 2015-2020, there have been twelve reported incidents of different nature, with a major oil spill in 2018 (250,000 L), and one in 2019 that occurred into the EEZ of the coastal state but extended outside the EEZ into the NRA. Other incidents included a near-miss collision between an iceberg and an oil platform in March 2017, and the occurrence of unauthorized discharges occurred in the recent years reveal the potential risks of offshore oil and gas activities in the NW Atlantic. There is a need to assess the cumulative impacts of human activities (*e.g.*, fisheries and oil and gas exploration/exploitation) on the NAFO ecosystems. Moreover, in order to a better understand of the contribution of each anthropogenic activity, impacts should be assessed both inside VME polygons and VME closure areas (*e.g.*, NAFO Closed Areas No 10 and No 2).

Information presented here, based on the results from the EU ATLAS research project and public information, will be useful to update the current 3LNO Ecosystem Summary Sheet (ESS) and to develop of the 3M EES.

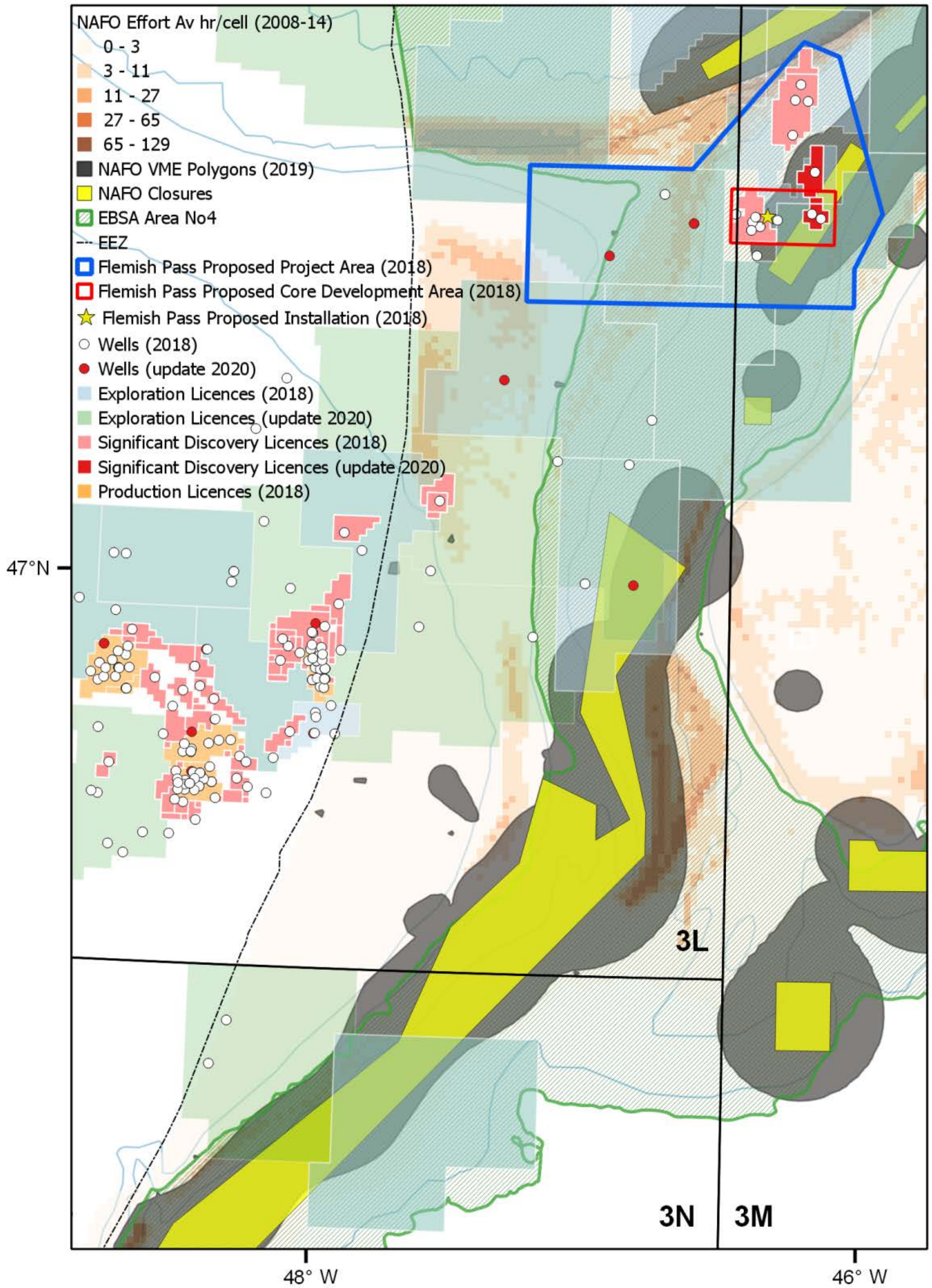

Figure 12.1. Updated map showing the geographical location of oil and gas activities in NAFO Divs. 3LMN. The map shows the potential conflicts between different users of the marine space (*e.g.,* oil and gas vs. fisheries) and between users and marine environment (oil and gas vs. VMEs). The yellow star indicates the location of the proposed production installation within the Bay du Nord Development Project in the Flemish Pass (outlined in blue). Information previously reported by WG-ESA (NAFO, 2018) and new available information (2020) is noted in brackets. Sources: NAFO, C-NLOPB, NESS and CBD.

Table 12.2. Updated list of recent offshore oil spills and other relevant incidents in the NW Atlantic, based on available information. Period 2015-2020 (source C-NLOPB).

Date	Incident description	Observations
20/07/2020	Unauthorized Discharge (Hibernia Platform)	Produced water discharge (mixture of seawater from the reservoir/used in injection, drilling and production fluids). The volume of the discharge and its composition are being determined
18/06/2020	Unauthorized Discharge (SeaRose FPSO), White Rose Field	1,098 L of an anti-microbial agent (X-Cide 450) was released along with 1,916,000 litres of water that were intended for reservoir injection.
17/08/2019	Hibernia Oil Spill	Estimated volume of oil on the water was 2,184 L at that time
17/07/2019	Hibernia Oil Spill	Oil expressed on the water could be in the order of 12,000 L. It occurred inside Canadian EEZ, but the analysis indicated that the oil was extended outside the EEZ and into the NAFO NRA[70]
16/10/2018	White Rose Field Oil Spill	250,000 L of oil were released to the environment
27/04/2018	Unauthorized Discharge of Synthetic Based Mud (SBM) (Transocean Barents platform)	28,000 L of SBM was released to the environment
29/03/2017	Near Miss - Iceberg Approaches Close to the SeaRose Floating Production, Storage and Offloading (FPSO) Vessel	A medium size iceberg came within 180 meters of the FPSO (about 340,000 barrels of crude oil on board at that time)
15/07/2016	Unauthorized Discharge/Impairment of safety critical equipment (Henry Goodrich drilling)	Approximately 1,800 L of hydraulic fluid was released to the environment
15/02/2016	Unauthorized Discharge of glycol (West Aquarius)	1,317 L of glycol was released to the sea
30/09/2015	Unauthorized Discharge of methanol (Terra Nova field)	3,000 L of methanol was released to the sea
31/08/2015	Major hydrocarbon gas release (Southern drill center)	8,938 kg of natural gas was released to the sea
28/07/2015	Major hydrocarbon gas release (Terra Nova FPSO)	10,000 kg of gas was released

[70] Ref. NAFO/19-205. 23 July 2019.

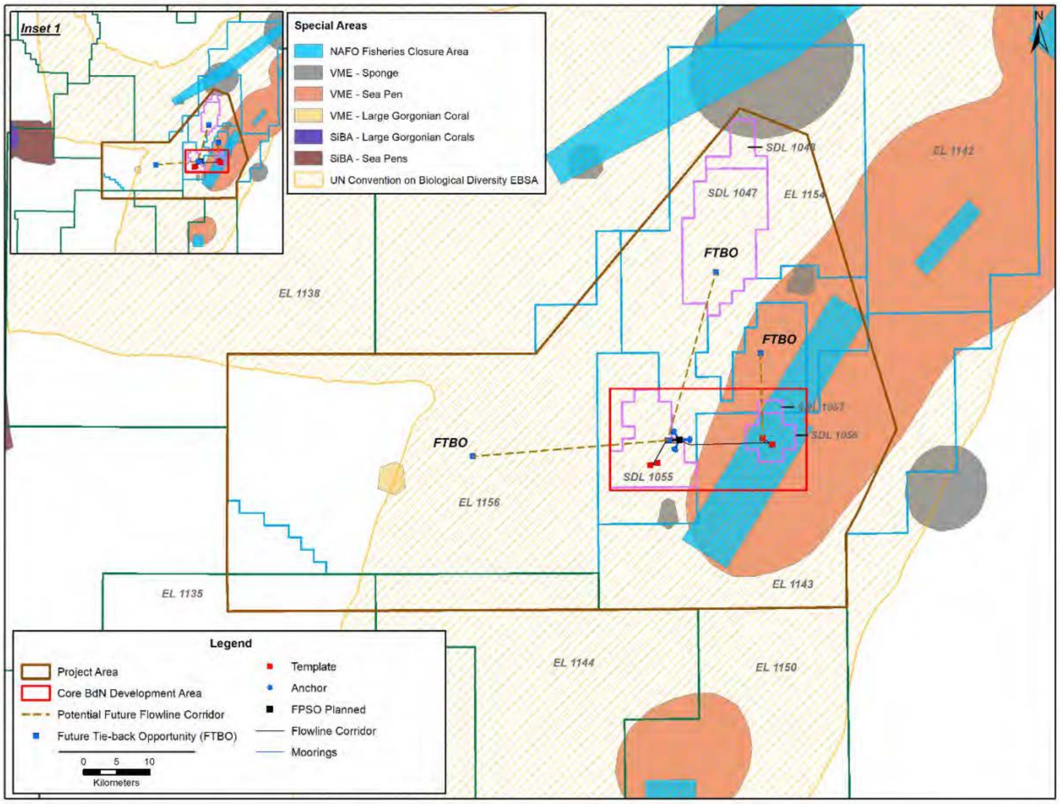

Figure 12.2. Details of the planned production installations (*i.e.*, templates, flowlines, FPSO vessel, anchors, moorings) within the Bay du Nord Development Project in the Flemish Pass (outlined in brown). The map shows the location of templates within NAFO Closed Area No 10 (sea pen) as well as potential tie-back opportunities inside VME polygon and close to the fishing grounds. The figure also shows the geographical location of two *Exploration Licences* (EL1144 and EL1150) mentioned in the text. Source: Equinor Canada Ltd. (2020)

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13. Other Business

a) Update from the Executive Secretary on a proposal for an MoU with the Sargasso Sea Commission

The Executive Secretary reported that the NAFO Secretariat has been approached by the Secretariat of the Sargasso Sea Commission (SSSC) about the possibility of signing a Memorandum of Understanding (MOU) between the two Secretariats. A draft text of the MOU was presented to the Working Group (EAFFM WP 20-04) and the Working Group was informed that the draft MOU will be presented to Scientific Council at the June 2021 meeting for advice as to how to proceed with the draft text. The Executive Secretary noted that the focus of the MOU was on marine scientific research and the collection of data, which would be of particular relevance for the SC and WG-ESA. The Executive Secretary added that a new 5-year Sargasso Sea Project, starting in 2022, has been established under a renewed Common Oceans Program using funding from the GEF (Global Environment Facility). Another Project under the renewed Common Oceans Program is the renewed ABNJ Deep Sea Fisheries Project, to be managed by the FAO, also starting in 2022. NAFO was a collaborating partner under a similar Project -- the previous ABNJ Deep Sea Project -- that ended in 2019 and is being requested by the FAO to continue to participate in this 'successor' Project.

The Executive Secretary also mentioned that he will be participating in a virtual Workshop organized by the International Seabed Authority (ISA) on the Development of a Regional Environmental Management Plan (REMP) for the Area of the Northern Mid-Atlantic Ridge, which will take place from 23 November to 04 December 2020. This is the first time NAFO has been invited by the ISA to such a Workshop.

The Executive Secretary also mentioned that NAFO is being requested to propose participants to an upcoming Workshop on Testing "Other effective area-based conservation measures" (OECMs) jointly organized by ICES and IUCN from 15 to 24 March – details of the Workshop are contained in COM Working Paper 20-40. Ellen Kenchington (CAN) is a co-Chair of this Workshop. One of the case studies proposed for the workshop is the "*NAFO closed areas to protect sponge Vulnerable Marine Ecosystems in ABNJ of Flemish Cap following UNGA sustainable fisheries resolutions*". Andrew Kenny (UK) expressed interest in participating in this Workshop.

b) Progress on implementation of the recommendation of the NAFO performance review

The Executive Secretary referred to the Working Paper prepared for the 2020 Annual Meeting concerning the Status of the Implementation of the Recommendations of the 2018 Performance Review of NAFO (COM WP 20-22) and noted that the proposed actions most relevant to WG-EAS include those proposed actions under recommendations number 1 development of NAFO's Ecosystem Approach Framework Roadmap), 14 (minimizing harmful impacts of fishing surveys in VME closed areas) and 15 (establishing codes for VME indicator species), and the additional COM recommendation (monitor relevant research related to the potential impact of activities other than fishing in the NAFO Convention Area and how these activities may impact fish stocks and biodiversity).

c) Date and place of next meeting

The next meeting will be held at the NAFO Secretariat offices, Nova Scotia, Canada from 16 to 25 November 2021.

APPENDIX 1: AGENDA: NAFO SCIENTIFIC COUNCIL (SC) WORKING GROUP ON ECOSYSTEM SCIENCE AND ASSESSMENT (WG-ESA)

By Correspondence, 17-26 November 2020

The meetings will be held virtually by WebEx. The WebEx will start at 07:30 Halifax time (11:30 GMT/UTC) each day to give participants the opportunity to log in early and test their audio connection. The meeting will open daily at 08:00 and generally run no later than 13:00 Halifax time.

Due to the reduced meeting format, agenda items highlighted in grey are not expected to be addressed during this meeting.

Provisional Agenda and Terms of Reference (ToRs)

1. Opening by the co-Chairs, Andrew Kenny (UK) and Pierre Pepin (Canada)
2. Appointment of Rapporteur
3. Adoption of Agenda
4. Review of 2019 WG-ESA recommendations and outcomes
5. Commission requests for advice on management in 2022 and beyond, requiring input from WG-ESA in 2020 to be presented at the Scientific Council meeting June 2021.

    a) (Com. Request #6). The Commission requests that Scientific Council, in preparation of the re-assessment of NAFO bottom fisheries in 2021 and discussion on VME fishery closures:

        i. Assess the overlap of NAFO fisheries with VME to evaluate fishery specific impacts in addition to the cumulative impacts for NRA fisheries;
        ii. Consider clearer objective ranking processes and options for objective weighting criteria for the overall assessment of significant adverse impacts and the risk of future adverse impacts;
        iii. Maintain efforts to assess all of the six FAO criteria including the three FAO functional SAI criteria which could not be evaluated in the current assessment.
        iv. Provide input and analysis of potential management options, with the goal of supporting meaningful and effective discussions between scientists and managers at the 2021 WG-EAFFM meeting;
        v. Continue to work on the VME indicator species as listed in Annex IE, Section VI to prepare for the next assessment.

    b) (Com. Request #5). The Commission requests that Scientific Council continue to refine work on the Ecosystem Road Map:

        i. Continue to test the reliability of the ecosystem production potential model and other related models
        ii. Report on these results to WG –EAFFM and WG-RBMS to further develop how it may apply to management decisions
        iii. Develop options of how ecosystem advice could inform management decisions, an issue which is directly linked to the results of the foreseen EAFM roadmap workshop.
        iv. Continue its work to develop models that support implementation of Tier 2 of the EAFM Roadmap.

    c) (Com. Request #18). The Commission request that Scientific Council proceed with developing the ecosystem summary sheets for 3M and 3LNO and move toward undertaking a joint Workshop with ICES (International Council for the Exploration of the Sea) as part of a peer review of North Atlantic ecosystems.

d) (Com. Request #7). The Commission requests that Scientific Council review the proposed revisions to Annex I.E, Part VI as reflected in COM/SC WG –EAFFM WP 18-01, for consistency with the taxa list annexed to the VME guide and recommend updates as necessary.

e) (Com. Request #16). The Commission requests Scientific Council to continue to monitor and provide updates resulting from relevant research related to the potential impact of activities other than fishing in the Convention Area. Further, that the Secretariat and the Scientific Council work with other international organizations, such as the FAO and ICES, to bring in additional expertise to inform the Scientific Council's work.

f) (Com. Request #17). The Commission requests the Scientific Council to provide information to the Commission at its next annual meeting on sea turtles, sea birds, and marine mammals that are present in NRA based on available data.

6. Other Business

a) Update from the Executive Secretary on a proposal for an MoU with the Sargasso Sea Commission

b) Progress on implementation of the recommendation of the NAFO performance review

c) Date and place of next meeting

7. Adjournment

ANNEX I. WG-ESA TERMS of REFERENCE

Theme 1: Spatial considerations.

ToR 1. Update on identification and mapping of sensitive species and habitats (VMEs) in the NAFO area.

1. *Update on VME indicator species data and VME indicator species distribution from EU and EU-Spain Groundfish Surveys.* ***Mar (only if time allows)***
2. The Commission requests that Scientific Council review the proposed revisions to Annex I.E, Part VI as reflected in COM/SC WG –EAFFM WP 18-01, for consistency with the taxa list annexed to the VME guide and recommend updates as necessary (Com. Request #7). **Ellen *et al.***
3. The Commission requests the Scientific Council to provide information to the Commission at its next annual meeting on sea turtles, sea birds, and marine mammals that are present in NRA based on available data (Com. Request #17). **Pablo and Nick**

Theme 2: Status, functioning and dynamics of NAFO marine ecosystems.

ToR 2. Update on recent and relevant research related to status, functioning and dynamics of ecosystems in the NAFO area.

1. Assessment of SAI – workplan (Com. Request #6):
    a) Up-date VME species biomass layers **- Ellen, Cam *et al.***
    b) Produce KDE polygons and thresholds for functions (bioturbation, nutrient cycling, structure forming, functional diversity) – **Ellen, Javi, Cam, Mariano *et al.***
    c) Up-date cumulative biomass vs fishing effort plots for ALL VMEs using new fishing effort and biomass data – **Anna, Andy, Mar *et al.***
    d) Create new cumulative functional (biomass) vs fishing effort plots for each function (bioturbation, nutrient cycling, structure forming, functional diversity) from trawl data. **Anna, Ellen, Javi, Cam, Mariano, Andy, Mar *et al.***
    e) Using VME species and Functional biomass polygon areas quantify the 3 impact assessment categories (low risk, high risk, impacted) for the SAI. **Anna, Ellen et al**
    f) Assess the spatial/temporal relationship between fish, invertebrates, VME indicator species and VMEs using multivariate approaches. **Anna, Andy *et al.***
    g) Up-date description of NRA fisheries – maps and tables. **Mar, Fernando, *et al.***
    h) Develop new VME fragmentation index. **Andy, Mariano.**
    i) Connectivity of VMEs Index. **Ellen, Mariano**
    j) VME buffer zones. **Ellen et al**
    k) Up-date literature review of VME recovery rates and functional significance. **Ellen *et al.***
    l) Up-date introductory sections to the SAI assessment report – **all**
    m) Up-date overall assessment of SAI **- all**

Theme 3: Practical application of ecosystem knowledge to fisheries management

ToR 3. Update on recent and relevant research related to the application of ecosystem knowledge for fisheries management in the NAFO area.

1. The Commission requests that Scientific Council continue to refine work on the Ecosystem Road Map (Com. Request #5):
    a) Continue to test the reliability of the ecosystem production potential model and other related models – **Mariano and Pierre**
    b) Report on these results to WG –EAFFM and WG-RBMS to further develop how it may apply to management decisions – **Pierre and Mariano**
    c) Develop options of how ecosystem advice could inform management decisions, an issue which is directly linked to the results of the foreseen EAFM roadmap workshop. **Andy, Pierre, Mariano, Carmen, Liz, Kate, Cristina, Ignacio**
    d) Continue its work to develop models that support implementation of Tier 2 of the EAFM Roadmap. **Mariano, Pierre *et al.***
2. The Commission request that Scientific Council proceed with developing the ecosystem summary sheets for 3M and 3LNO and move toward undertaking a joint Workshop with ICES (International

Council for the Exploration of the Sea) as part of a peer review of North Atlantic ecosystems. (Com. Request #18). **Pierre *et al.***

3. The Commission requests Scientific Council to monitor and provide regular updates on relevant research related to the potential impact of activities other than fishing in the Convention Area, such as oil exploration, shipping and recreational activities, and how they may impact the stocks and fisheries as well as biodiversity in the Regulatory Area. **Pablo *et al.***
4. Up-dated gridded data layers for, i. VME species biomass, ii. VME functional biomass, iii. fishing effort (VMS trawl line density), iv. haul-by-haul catch biomass (landings), and determining a set of management options for new or revised VME closures (Com. Request #6) **- Anna, Ellen, Cam, Mar, Neil *et al.***

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