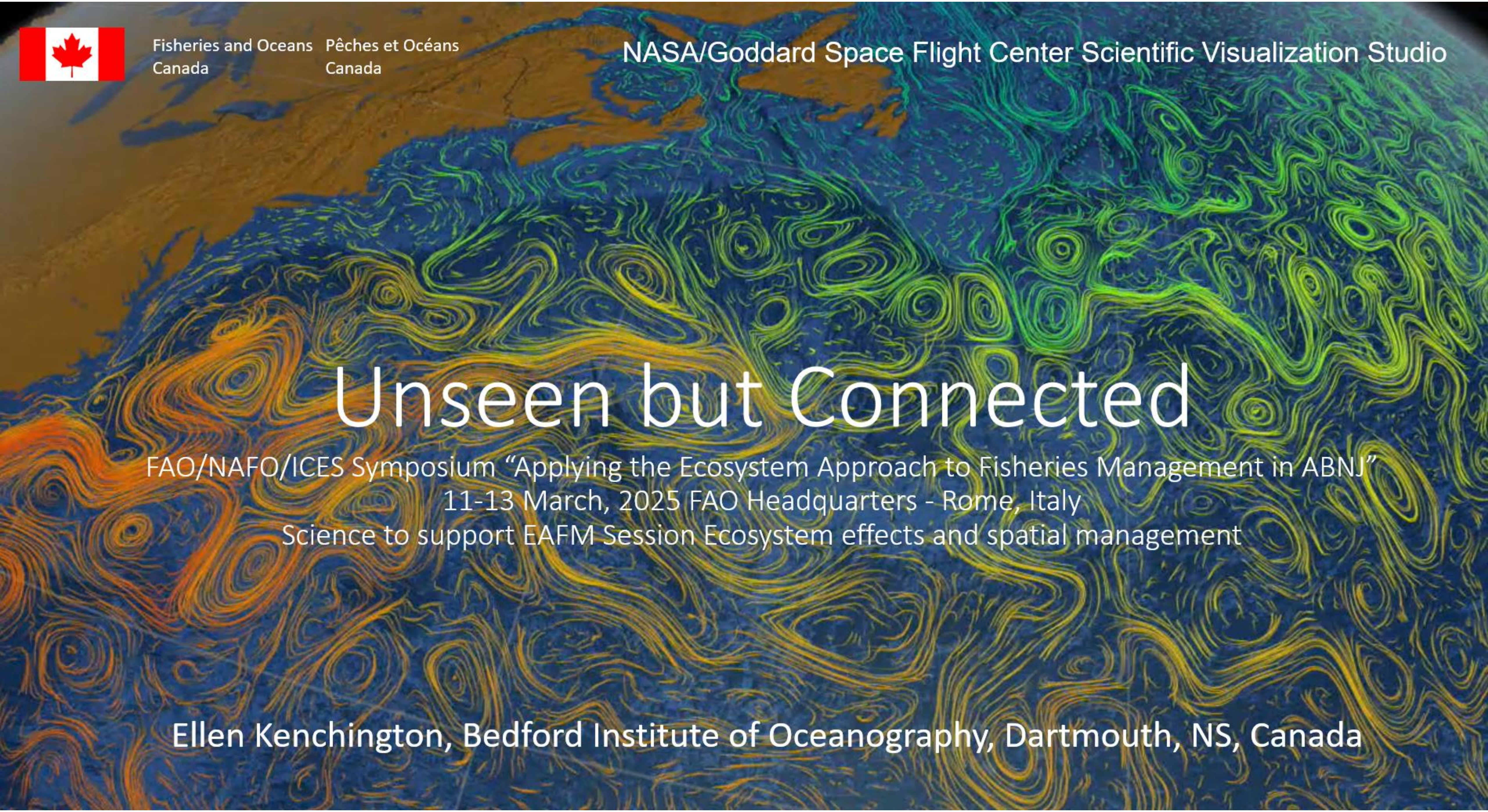


Fisheries and Oceans Canada
Pêches et Océans Canada

NASA/Goddard Space Flight Center Scientific Visualization Studio

Unseen but Connected

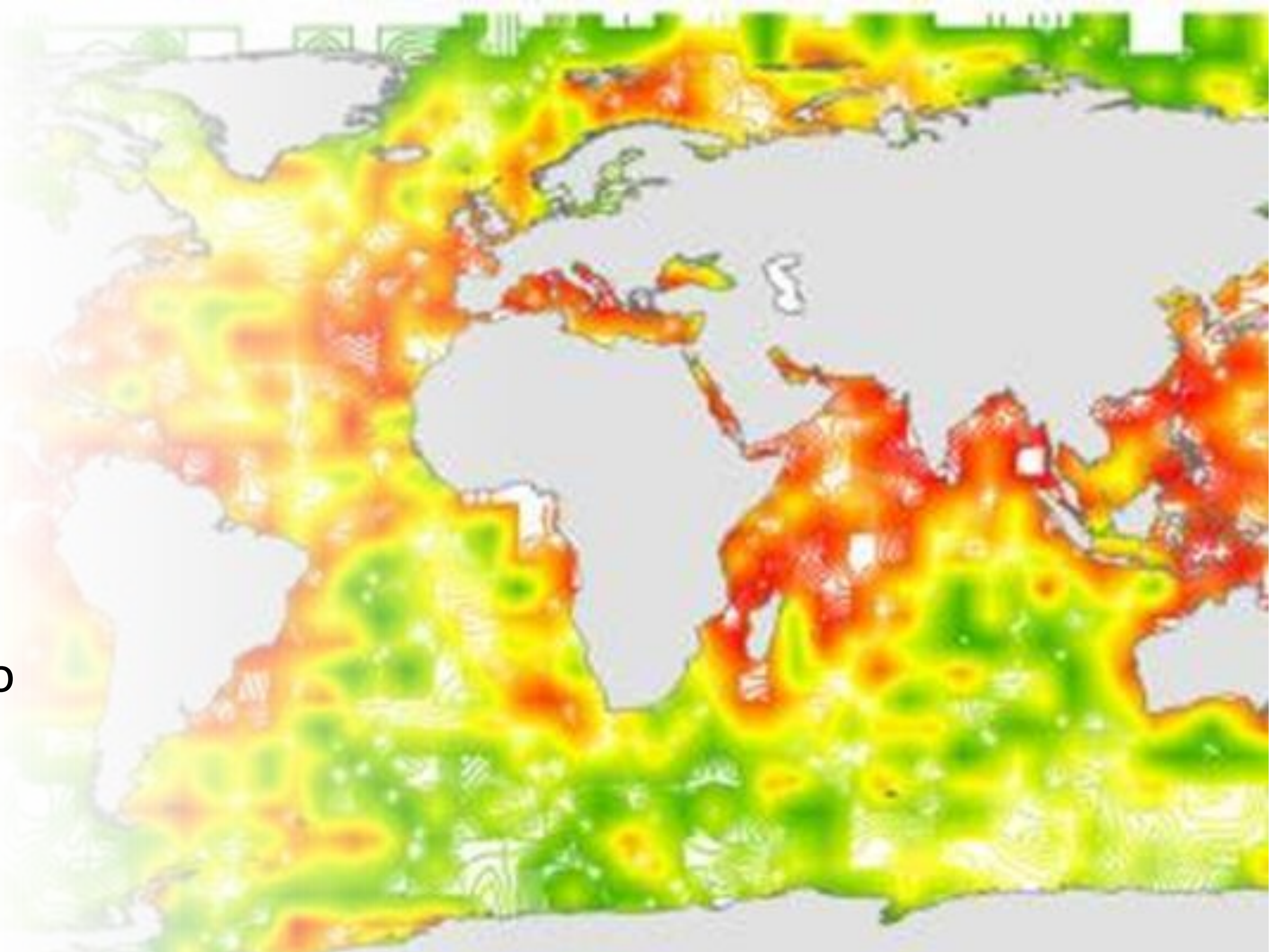
FAO/NAFO/ICES Symposium “Applying the Ecosystem Approach to Fisheries Management in ABNJ”
11-13 March, 2025 FAO Headquarters - Rome, Italy
Science to support EAFM Session Ecosystem effects and spatial management

Ellen Kenchington, Bedford Institute of Oceanography, Dartmouth, NS, Canada

Movement is a key property of connectivity occurring over a range of spatial scales and can be active or passive

Ecosystem Effects and Spatial Management

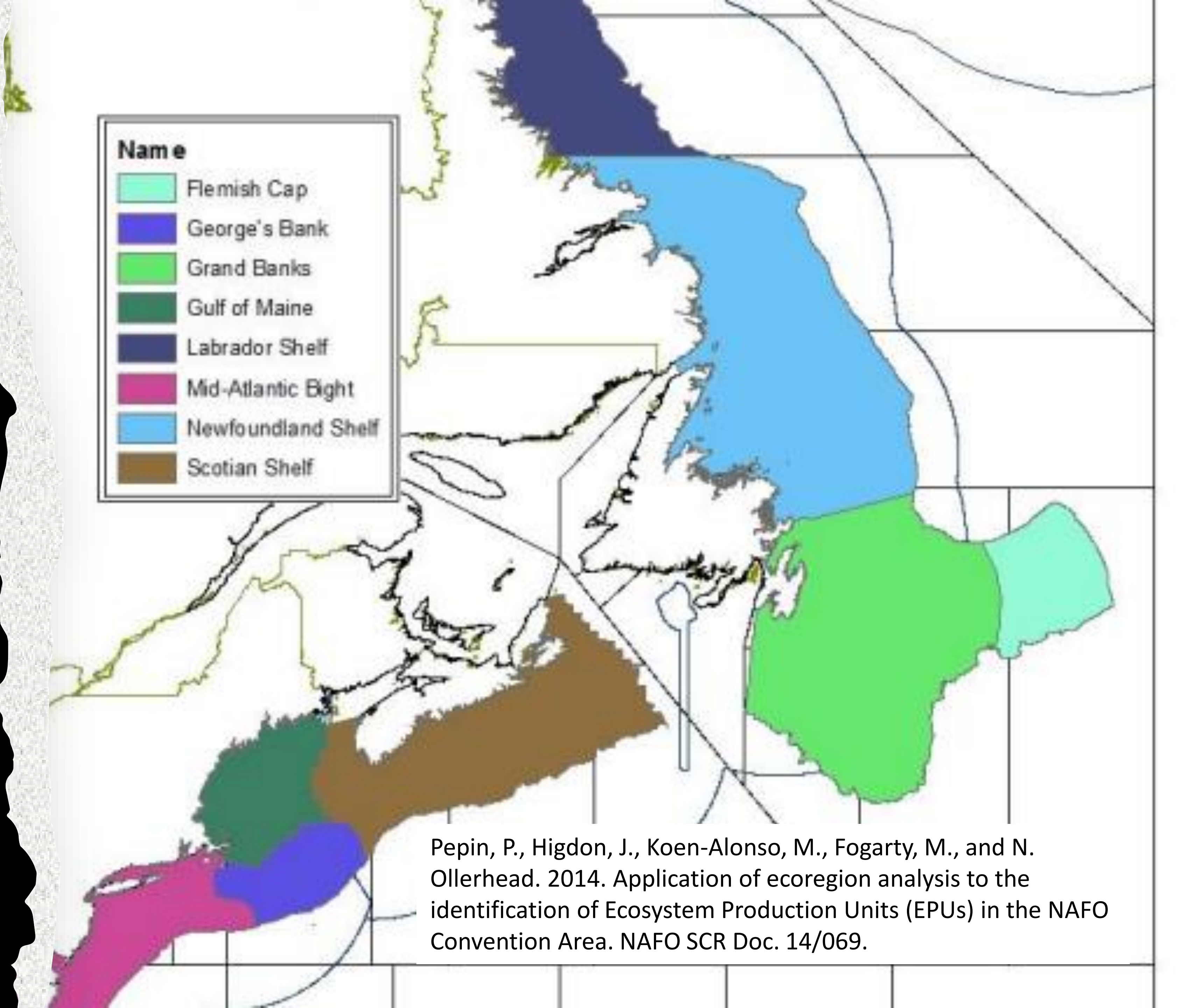
Dispersal drives population dynamics, community structure, adaptation and speciation and so is an essential component to consider in an EAFM



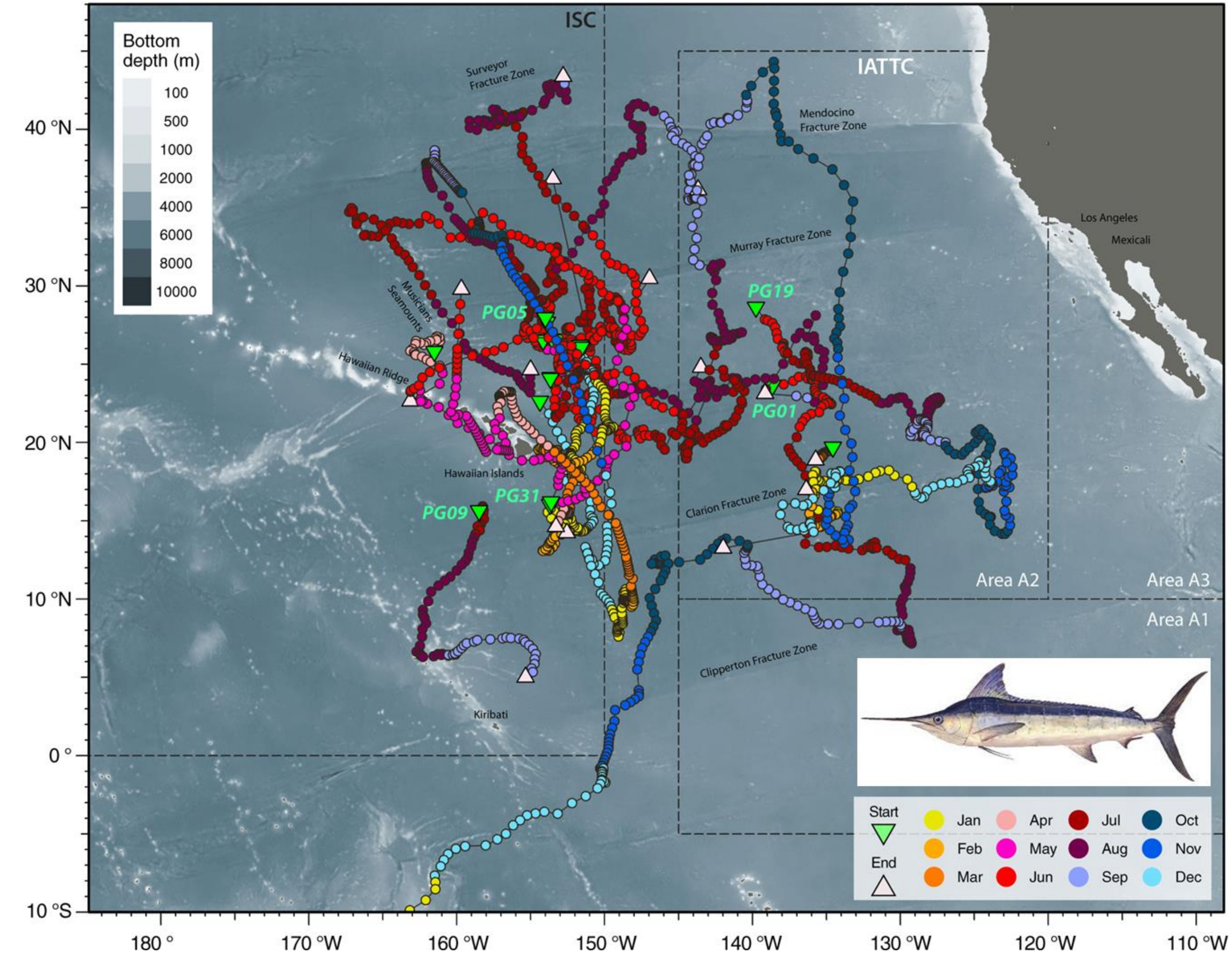
Costello, M.J., Chaudhary, C. (2017) Marine Biodiversity, Biogeography, Deep-Sea Gradients, and Conservation. Current Biology 27(11), R511-R527 https://www.sciencedirect.com/science/article/pii/S0960982217305055

Bioregion, Ecosystem Production Unit (EPU), and Ecoregion

The distribution ranges of major marine resources and fish stocks helped to inform the establishment of three nested spatial scales relevant for the development of ecosystem summaries and management plans.

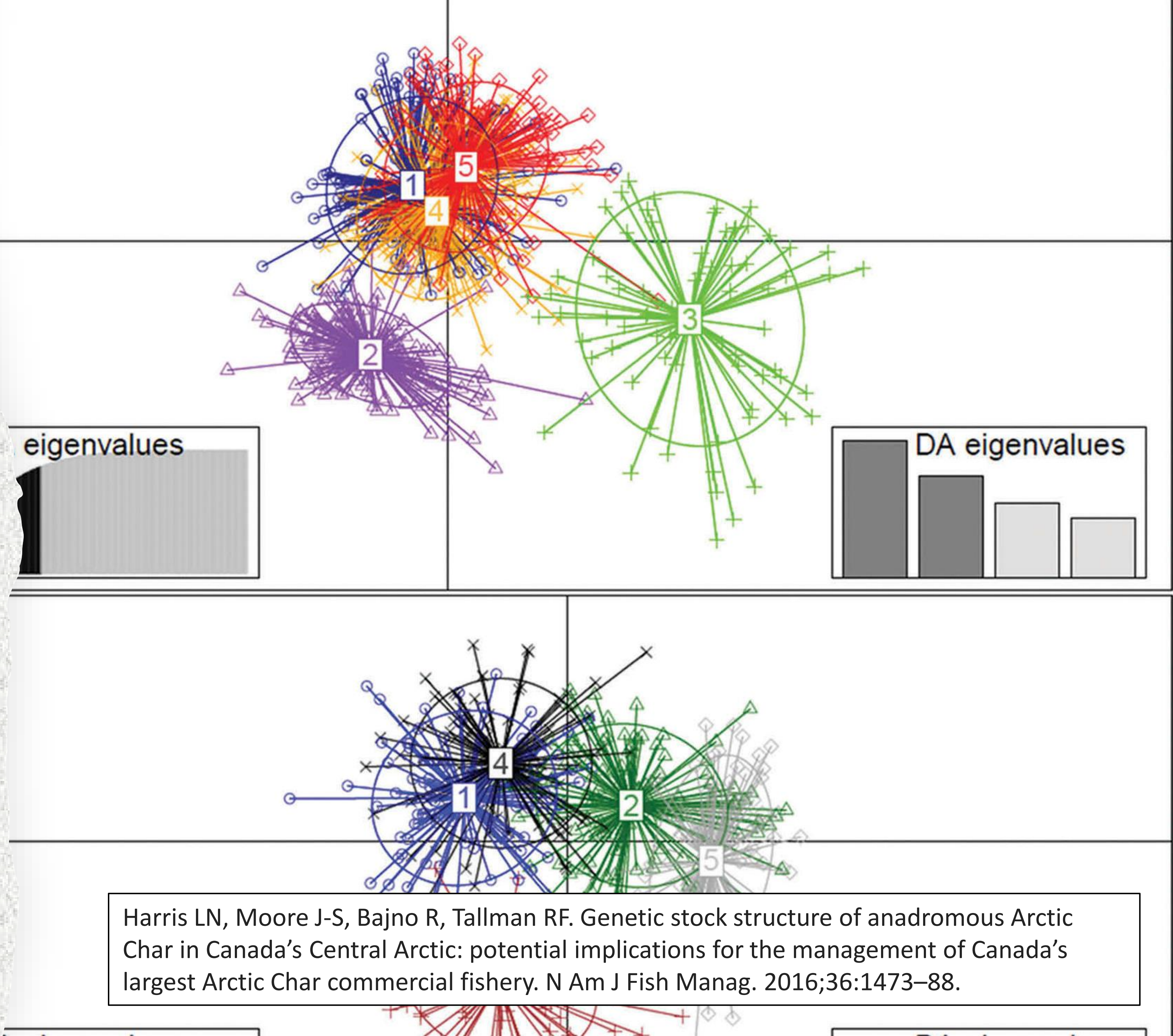


Pepin, P., Higdon, J., Koen-Alonso, M., Fogarty, M., and N. Ollerhead. 2014. Application of ecoregion analysis to the identification of Ecosystem Production Units (EPUs) in the NAFO Convention Area. NAFO SCR Doc. 14/069.



Lam CH, Tam C and Lutcavage ME (2022) Connectivity of Striped Marlin From the Central North Pacific Ocean. *Front. Mar. Sci.* 9:879463

Genetic connectivity is a measure of how well genes are exchanged between populations and is used to identify fish stocks.



Harris LN, Moore J-S, Bajno R, Tallman RF. Genetic stock structure of anadromous Arctic Char in Canada’s Central Arctic: potential implications for the management of Canada’s largest Arctic Char commercial fishery. N Am J Fish Manag. 2016;36:1473–88.

For sessile and sedentary benthic species such as the coral and sponge vulnerable marine ecosystem (VME) indicators, connectivity within and among high density patches is a key process influencing colonization.

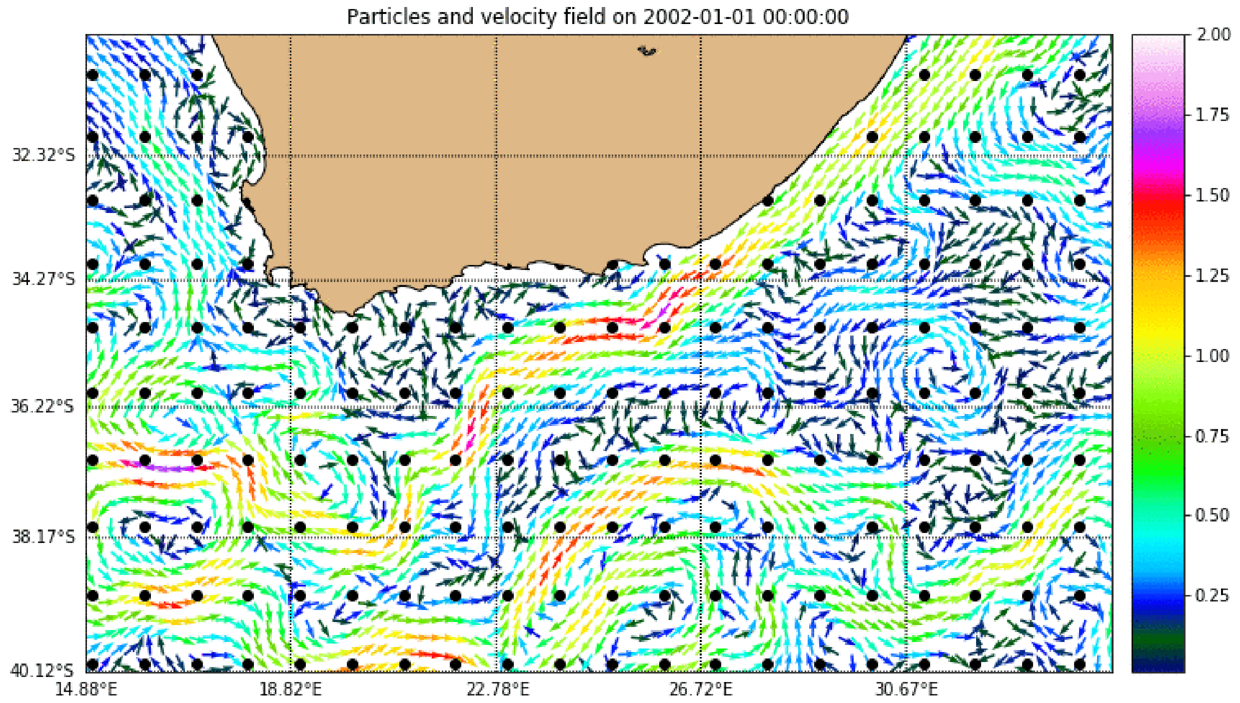
In such species, connectivity is governed by larval transport, predominantly mediated through ocean bottom currents.

Ruth Gates Restoration Innovation Grants Credit: Johnston Applied Marine Science

Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

Lagrangian Particle Tracking Models

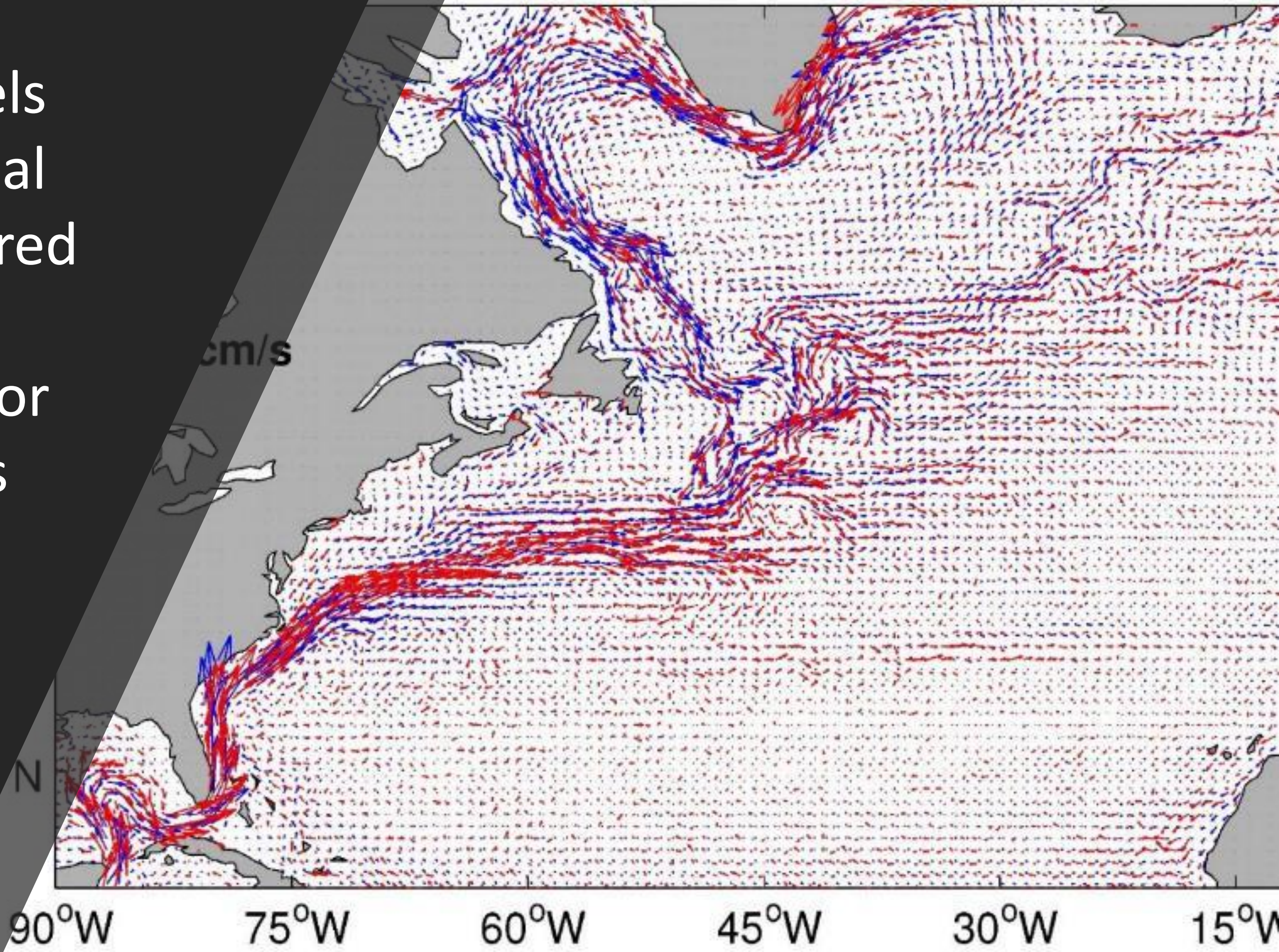
User Interface; Individual-level models of particles; Realistic 3-D oceanographic model of the physics



OceanParcels

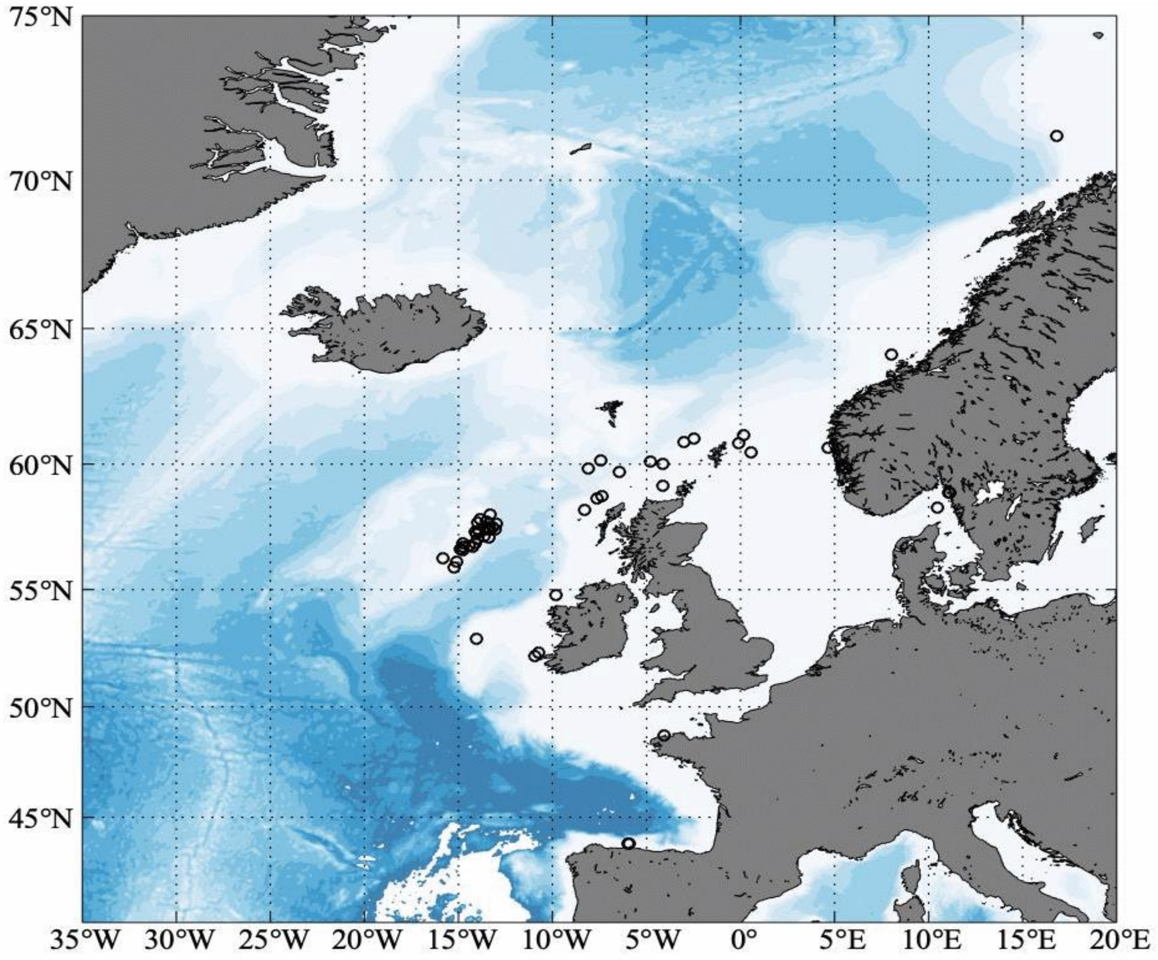
Physical oceanographic models are available at global, regional and local scales using structured (e.g., NEMO) or unstructured grids (e.g., FVCOM) suitable for open ocean and coastal areas respectively

Surface currents from the BNAM ocean model (blue) and observational surface drifter data (red).



Wang, Z., Brickman, D. and Greenan, B. J. W. (2019). Deep. Sea. Res. I 149, 103056. doi: 10.1016/j.dsr.2019.06.002

Connectivity - Lagrangian Particle Tracking Models and Genetics

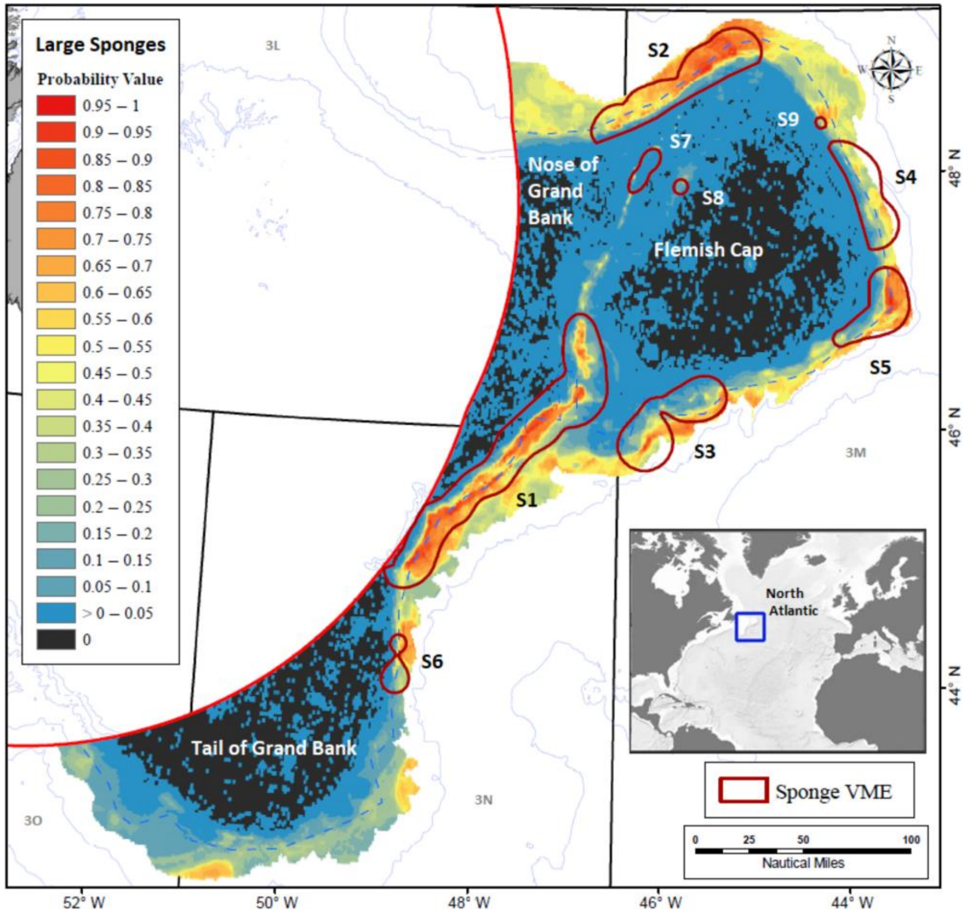


Taboada, S. et al. (2023) Long distance dispersal and oceanographic fronts shape the connectivity of the keystone sponge *Phakellia ventilabrum* in the deep northeast Atlantic. Frontiers in Marine Science 10:1177106. https://doi.org/10.3389/fmars.2023.1177106

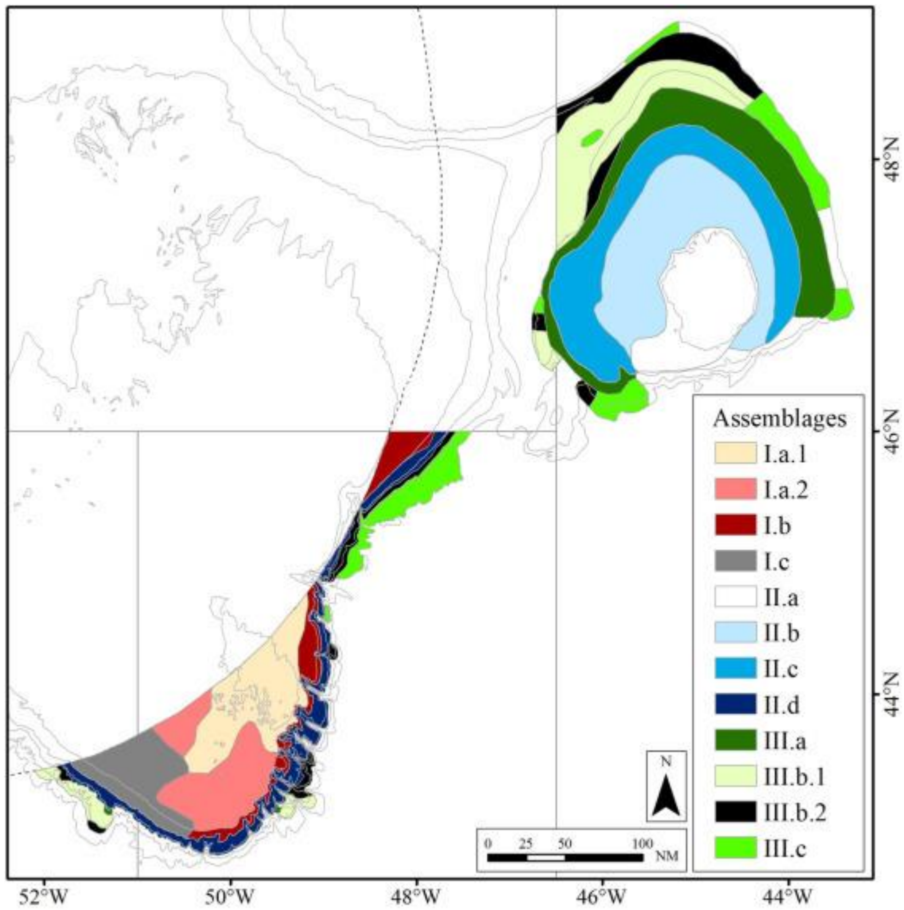
Examples of connectivity being used to inform decisions at different spatial scales

Vulnerable marine ecosystems in NAFO

Ecoregions: regional habitat scale



WANG, S., E. KENCHINGTON, F.J. MURILLO, C. LIRETTE, Z. WANG, M. KOEN-ALONSO, A. KENNY, M. SACAU & P. PEPIN, 2024. Quantifying the effects of habitat fragmentation in deep-sea vulnerable marine ecosystems. Diversity and Distributions 30 (5):e13824. https://doi.org/10.1111/ddi.13824

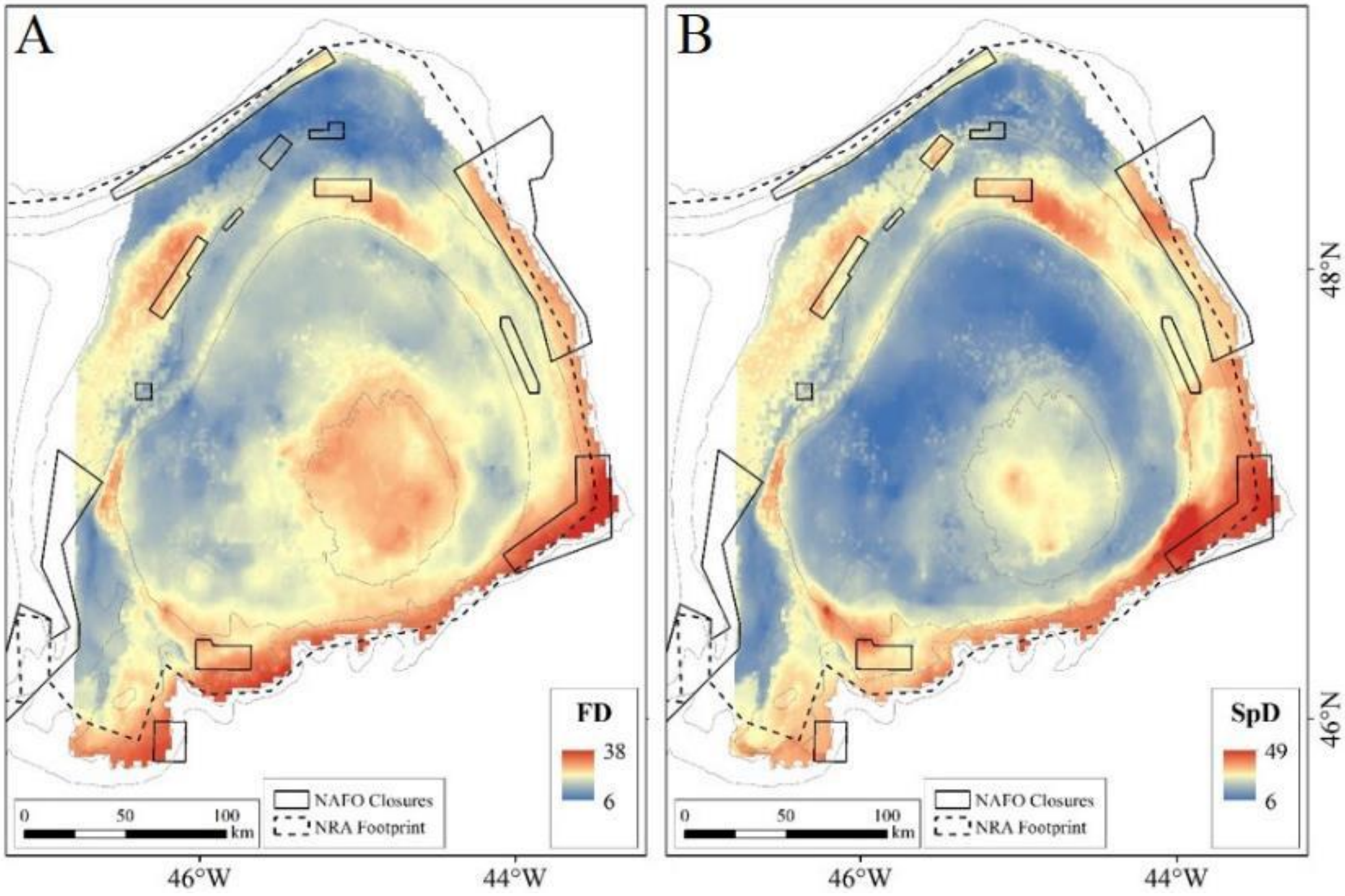


MURILLO F.J., A. SERRANO, E. KENCHINGTON & J. MORA, 2016. Epibenthic assemblages of the Tail of the Grand Bank and Flemish Cap (northwest Atlantic) in relation to environmental parameters and trawling intensity. Deep Sea Research I 109: 99-122.

Mapping of Ecosystem Functions at the EPU Scale

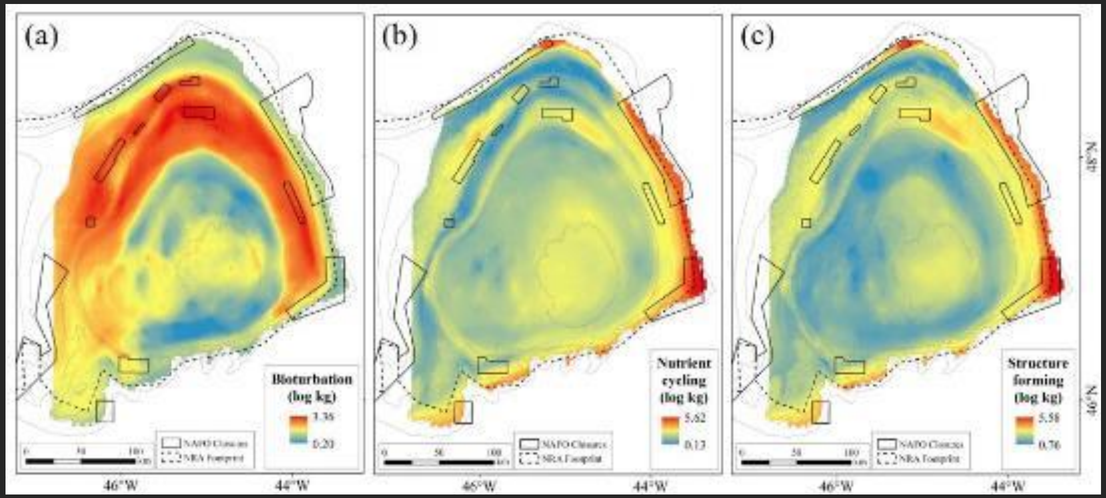
Predicted Fric (Functional Diversity)

Predicted Species Density



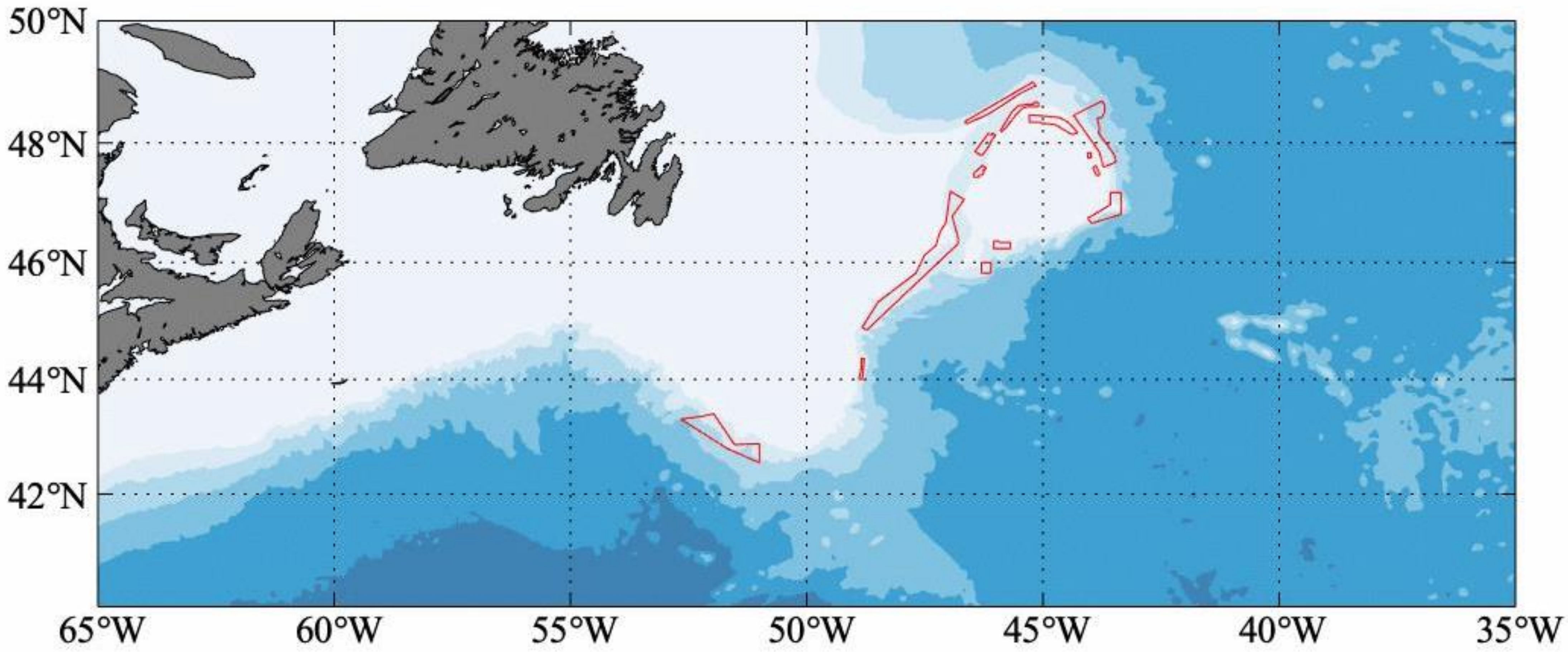
MURILLO, F.J., E. KENCHINGTON, M. KOEN-ALONSO, J. GUIJARRO, T.J. KENCHINGTON, M. SACAU, L. BEAZLEY & H.T. RAPP, 2020. Mapping benthic ecological diversity and interactions with bottom-contact fishing on the Flemish Cap (northwest Atlantic). *Ecological Indicators* 112: 106135. https://doi.org/10.1016/j.ecolind.2020.106135

Bioturbation Nutrient Cycling Habitat Provision



MURILLO, F.J., B. WEIGEL, E. KENCHINGTON & M. BOUCHARD MARMEN, 2020. Marine epibenthic functional diversity on Flemish Cap (northwest Atlantic) – identifying trait responses to the environment and mapping ecosystem functions. *Diversity and Distributions* 26 (4): 460-478.

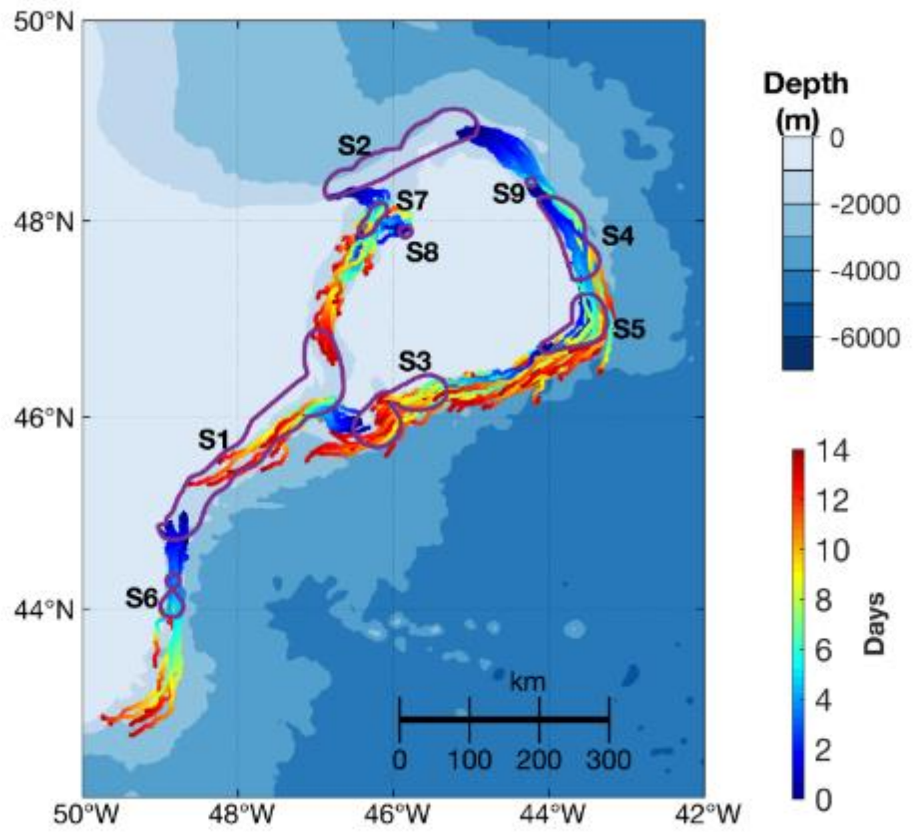
Ecoregions and Ecosystem Production Unit Connectivity

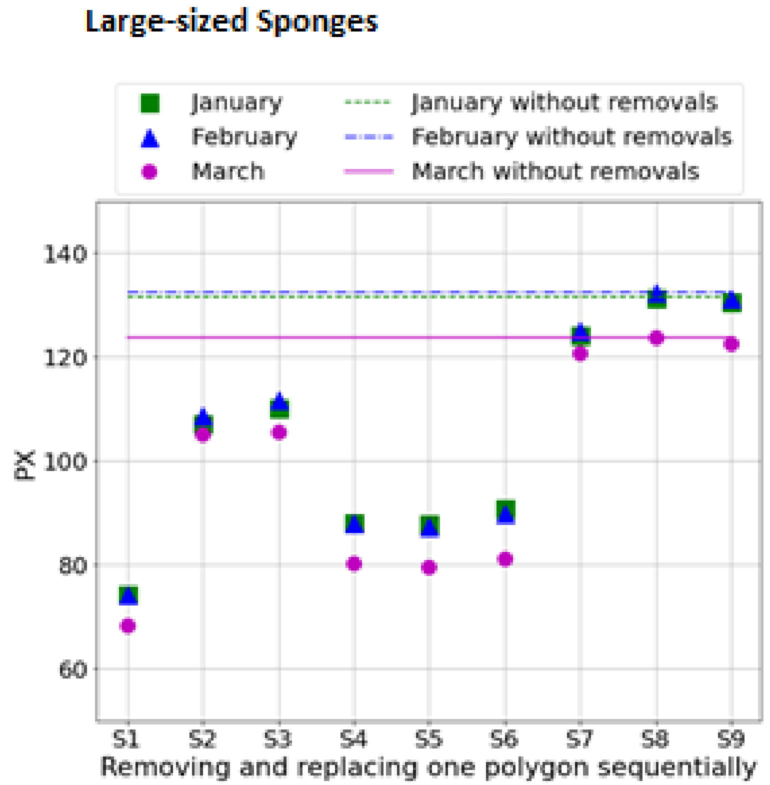


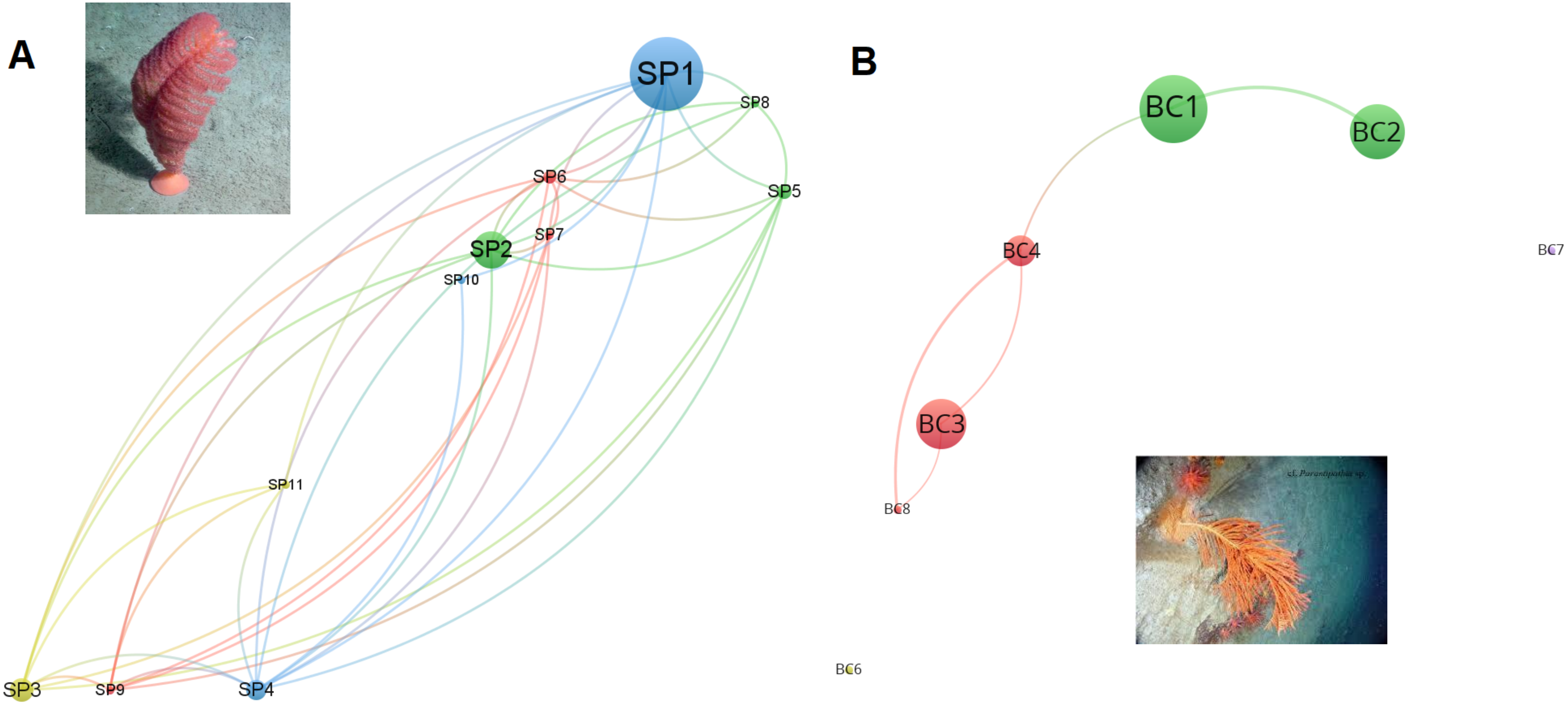
WANG, S., E.L. KENCHINGTON, Z. WANG, I. YASHAYAEV & A.J. DAVIES, 2020. 3-D Ocean particle tracking modeling reveals extensive vertical movement and downstream interdependence of closed areas in the northwest Atlantic. *Nature Scientific Reports* 10, 21421 (2020). https://doi.org/10.1038/s41598-020-76617-x

Connectivity Network Simulations

WANG, S., E. KENCHINGTON, F.J. MURILLO, C. LIRETTE, Z. WANG, M. KOEN-ALONSO, A. KENNY, M. SACAU & P. PEPIN, 2024. Quantifying the effects of habitat fragmentation in deep-sea vulnerable marine ecosystems. Diversity and Distributions 30 (5):e13824. https://doi.org/10.1111/ddi.13824







WANG, S., E. KENCHINGTON, F.J. MURILLO, C. LIRETTE, Z. WANG, M. KOEN-ALONSO, A. KENNY, M. SACAU & P. PEPIN, 2024. Quantifying the effects of habitat fragmentation in deep-sea vulnerable marine ecosystems. Diversity and Distributions 30 (5):e13824. https://doi.org/10.1111/ddi.13824

TABLE 2 Percentage declines in PX from simulated removal of individual patches, averaged across various particle tracking models, ordered by magnitude (see also Tables S8–S14) and taxon-specific grand mean (bold).

Black coral		Sponges		Small gorgonian corals		Large gorgonian corals		Sea pens		Bryozoans		Tunicates	
Patch	Decline in PX	Patch	Decline in PX	Patch	Decline in PX	Patch	Decline in PX	Patch	Decline in PX	Patch	Decline in PX	Patch	Decline in PX
BC1[a] (2/1)	49.0	S1[a] (1/3)	45.3	SGC4 (1/6)	61.9	LGC1[a] (3/5)	88.7	SP1[a] (10/2)	86.6	BR1 (4/10)	70.7	TU1 (3/13)	87.9
BC3[a] (1/1)	43.9	S5[a] (1/3)	34.0	SGC3 (2/4)	58.8	LGC9 (0/2)	83.7	SP6[a] (4/4)	46.1	BR2 (6/5)	29.2	TU2 (5/4)	10.1
BC8[a] (0/2)	37.8	S4[a] (2/2)	33.5	SGC5 (3/5)	21.7	LGC3[a] (4/1)	12.3	SP2[a] (4/5)	6.3	BR4 (3/3)	14.0	TU8 (1/5)	9.2
BC4[a] (2/1)	26.5	S6[a] (0/1)	33.0	SGC1 (0/6)	18.6	LGC2[a] (3/0)	10.7	SP3 (1/8)	4.3	BR6 (2/2)	1.5	TU3 (3/10)	7.2
BC2[a] (1/1)	23.5	S2[a] (4/1)	16.4	SGC6[a] (4/2)	3.1	LGC4 (0/6)	<0.05	SP9 (1/8)	4.2	BR5 (1/2)	1.3	TU5 (0/8)	0.5
BC5 (0/0)	<0.05	S3[a] (1/1)	16.2	SGC7 (4/1)	3.0	LGC5 (0/2)	<0.05	SP5[a] (7/2)	2.3	BR7 (2/3)	0.8	TU4 (5/3)	0.3
BC6 (0/0)	<0.05	S7[a] (2/2)	4.2	SGC2[a] (6/0)	2.0	LGC6 (1/3)	<0.05	SP8[a] (5/2)	2.3	BR8 (2/0)	0.1	TU9 (5/2)	0.1
BC7[a] (0/0)	<0.05	S9[a] (3/1)	0.8	SGC8 (3/0)	<0.05	LGC7 (2/1)	<0.05	SP7 (5/2)	0.9	BR9 (2/0)	0.1	TU10 (5/3)	0.1
		S8 (2/0)	0.1	SGC9 (1/0)	<0.05	LGC8 (2/0)	<0.05	SP4 (2/8)	0.7	BR11 (2/0)	0.1	TU11 (4/4)	0.1
						LGC10 (2/0)	<0.05	SP10[a] (1/1)	<0.05	BR12 (1/1)	0.1	TU6 (3/0)	<0.05
						LGC11 (0/0)	<0.05	SP11 (3/1)	<0.05	BR13 (0/1)	0.1	TU7 (0/0)	<0.05
						LGC12 (3/0)	<0.05			BR14 (3/2)	0.1	TU12 (6/0)	<0.05
										BR17 (2/0)	0.1	TU13 (2/2)	<0.05
										BR3 (0/0)	<0.05	TU14 (3/1)	<0.05
										BR10[a] (0/0)	<0.05	TU15 (3/0)	<0.05
										BR15 (0/1)	<0.05	TU16 (1/0)	<0.05
										BR16[a] (0/0)	<0.05	TU17 (6/0)	<0.05
												TU18[a] (0/0)	<0.05
	22.6		**20.4**		**18.8**		**16.3**		**14.0**		**7.0**		**6.8**

Note: Results are colour-coded by classes defined using Jenks natural breaks classification. Class 1 is indicated in dark blue and signifies declines in PX of >58.81%; Class 2 is indicated in light blue and signifies declines in PX of <48.98% and >18.57%. All others are Class 3 (see Supplementary Table S15). The outdegree and indegree connectance of the patches are also provided (outdegree/indegree).

[a]Indicates that the patch is currently partially protected from area closures prohibiting bottom-contact fishing (NAFO, 2023).

Agent-based Modeling at the Bioregion Scale

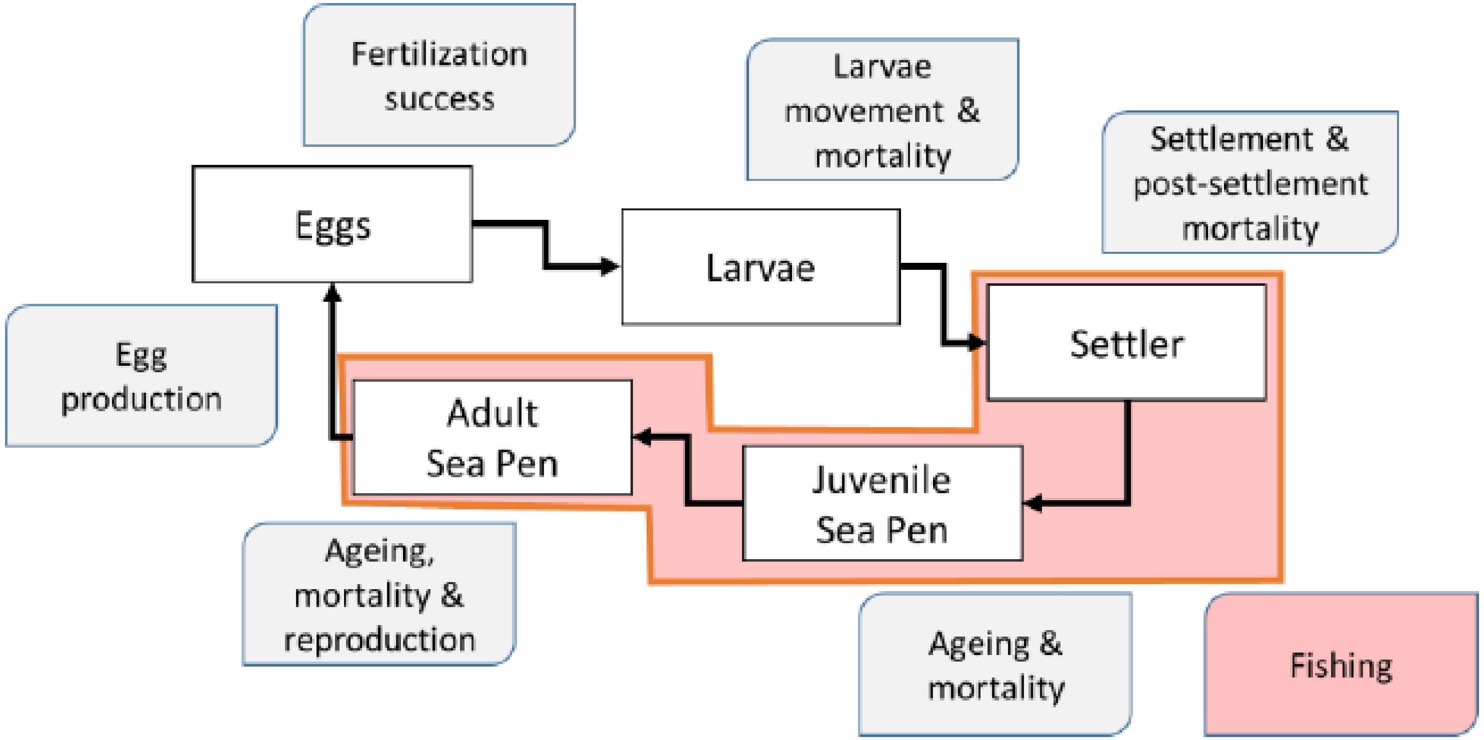
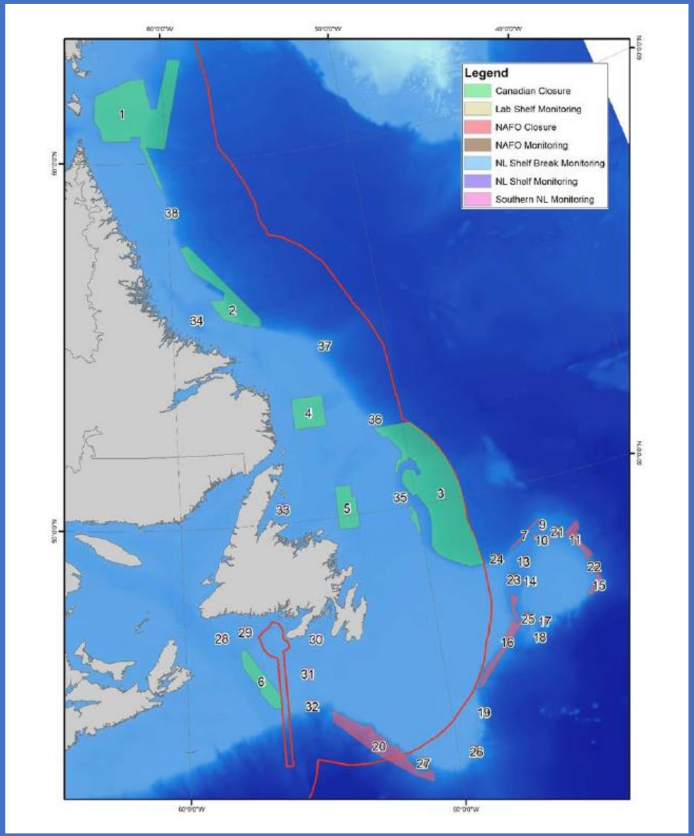
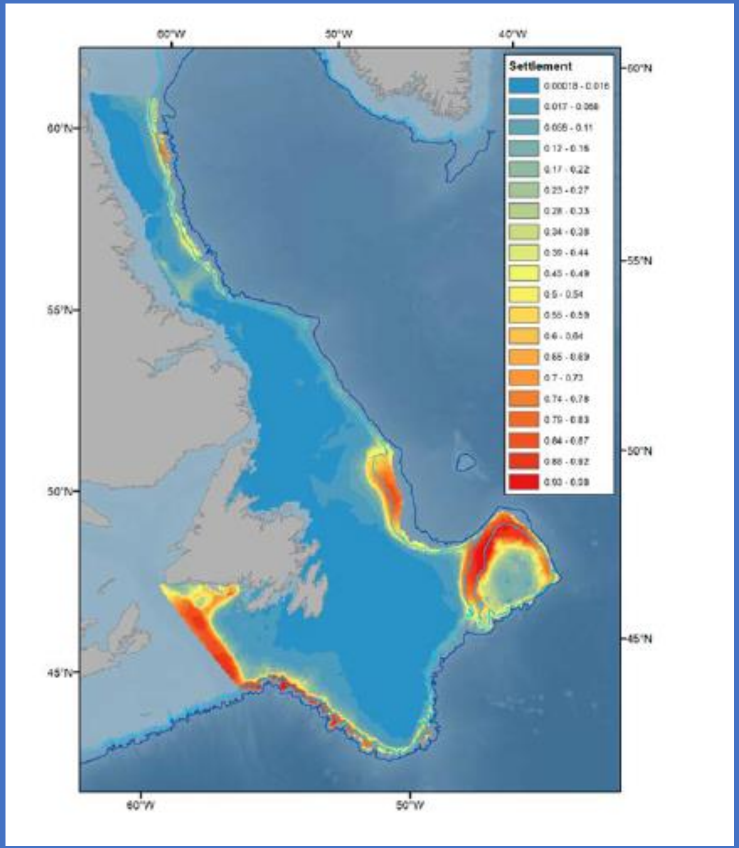


Figure 7.1. Schematic description of the life history stages/processes incorporated in the sea pen ABM. The red background indicates the life history stages impacted by fishing.

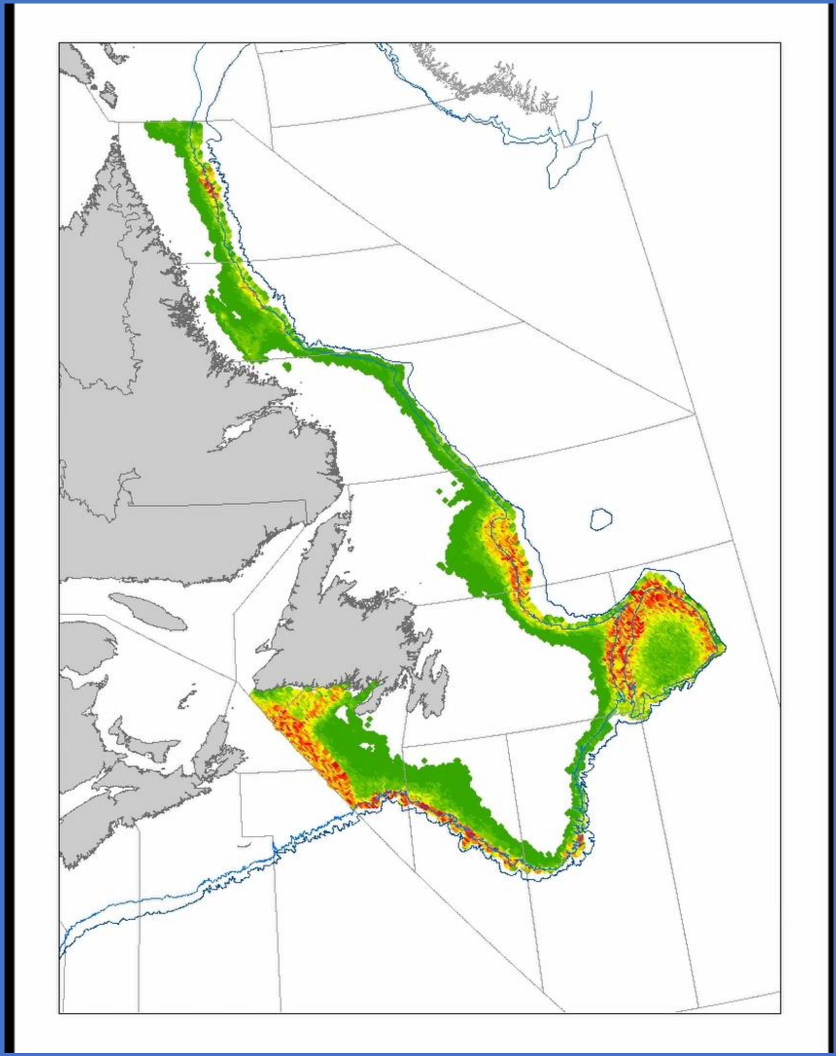
NAFO. 2019. Report of the 12th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO SCS Doc. 19/25, Serial No. N7027, 135 p.



Closed Area Network



Sea Pen Settlement Surface

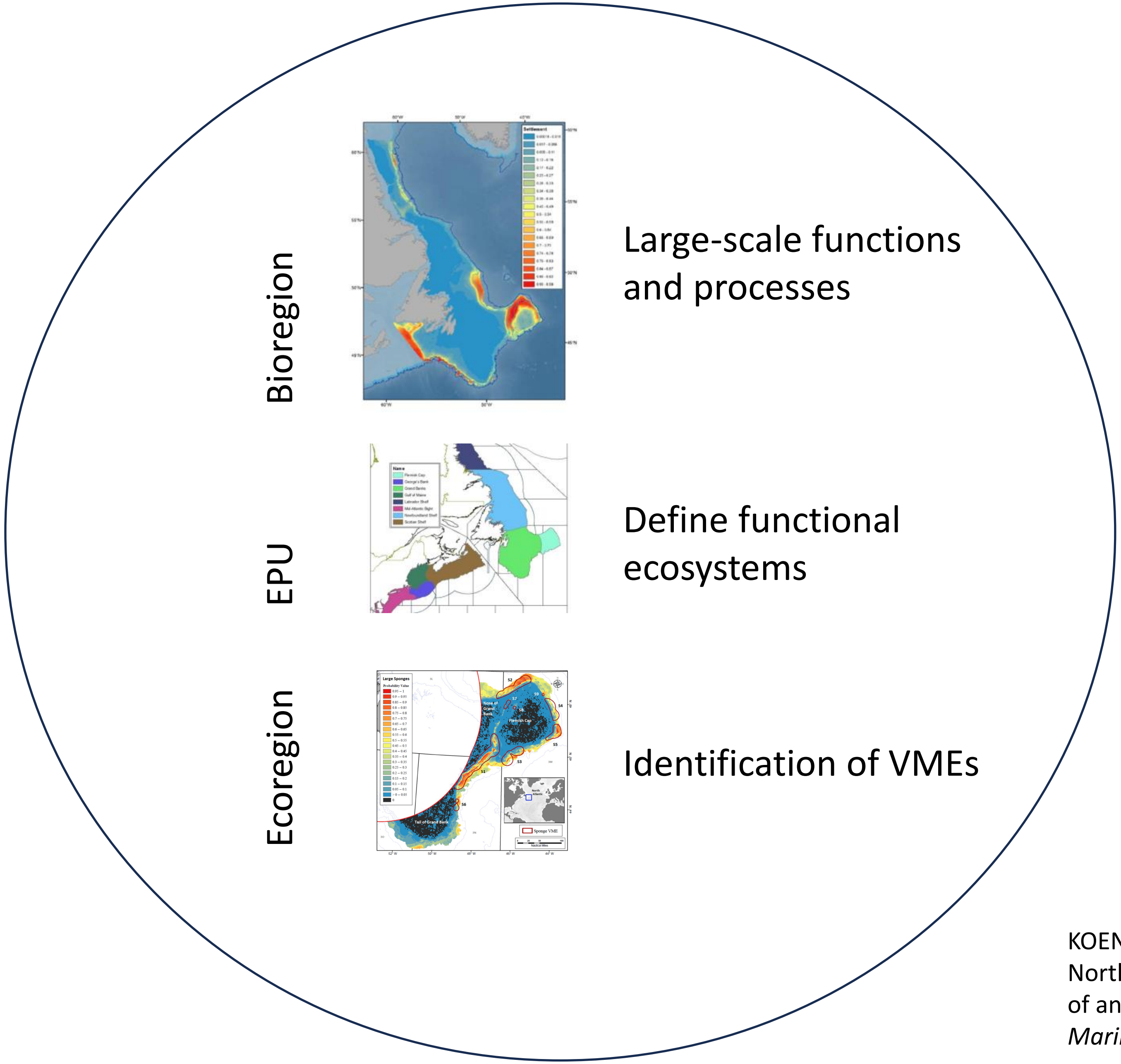


Adding the average fishing effort using VMS fishing effort data

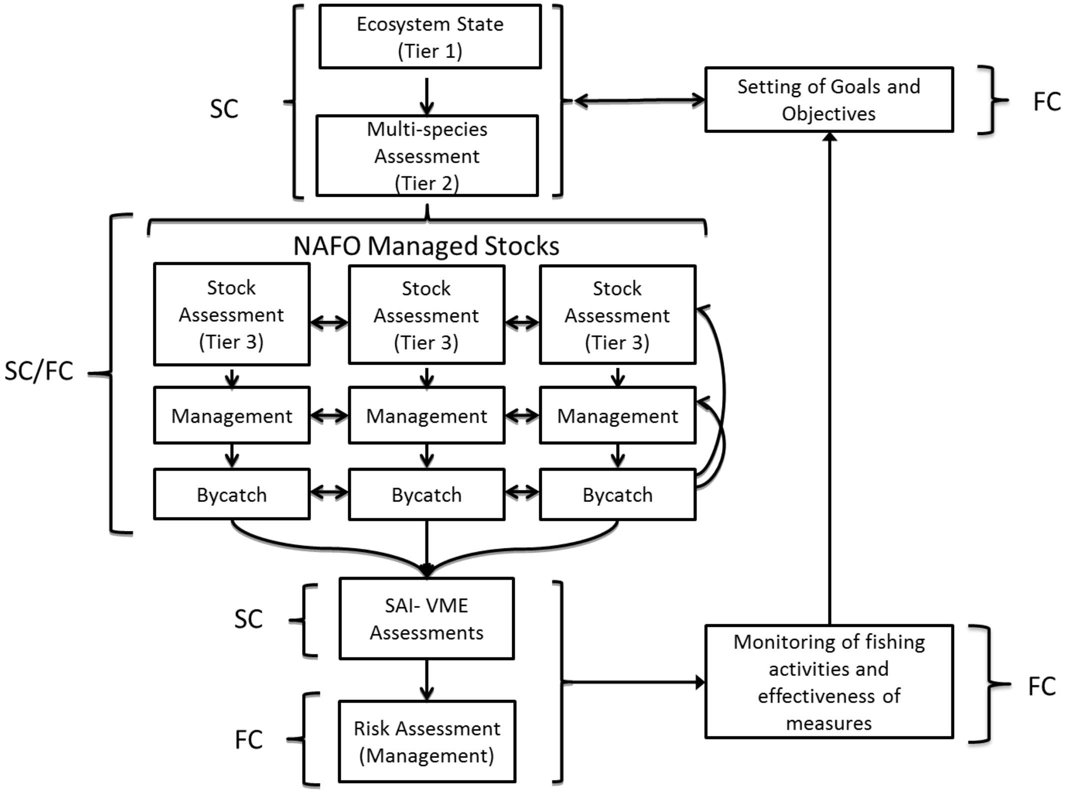
Table 12.2. Rating guide based on expert judgement used to evaluate the effectiveness of area closures put in place to protect vulnerable marine ecosystems in the NAFO Regulatory Area and the need for management actions. Connectivity is defined here as physical links between two or more areas; an area is considered to have redundancy when two or more other areas connect to it. These properties relate to the ability of populations to persist. 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.

Recommendation	Proportion of VME Protected	Projected Connectivity Among Closures	Management Action
Good	> 60% VME	Good connectivity among closures	Beneficial
Adequate	> 60% VME	Limited connectivity or redundancy	
Incomplete	60% - 30% VME	Good connectivity among closures	Desirable
Limited	60% - 30% VME	Limited connectivity or redundancy	
Poor	30% - 15% VME	Limited connectivity or redundancy	Essential
Inadequate	< 15% VME	Limited connectivity or redundancy	

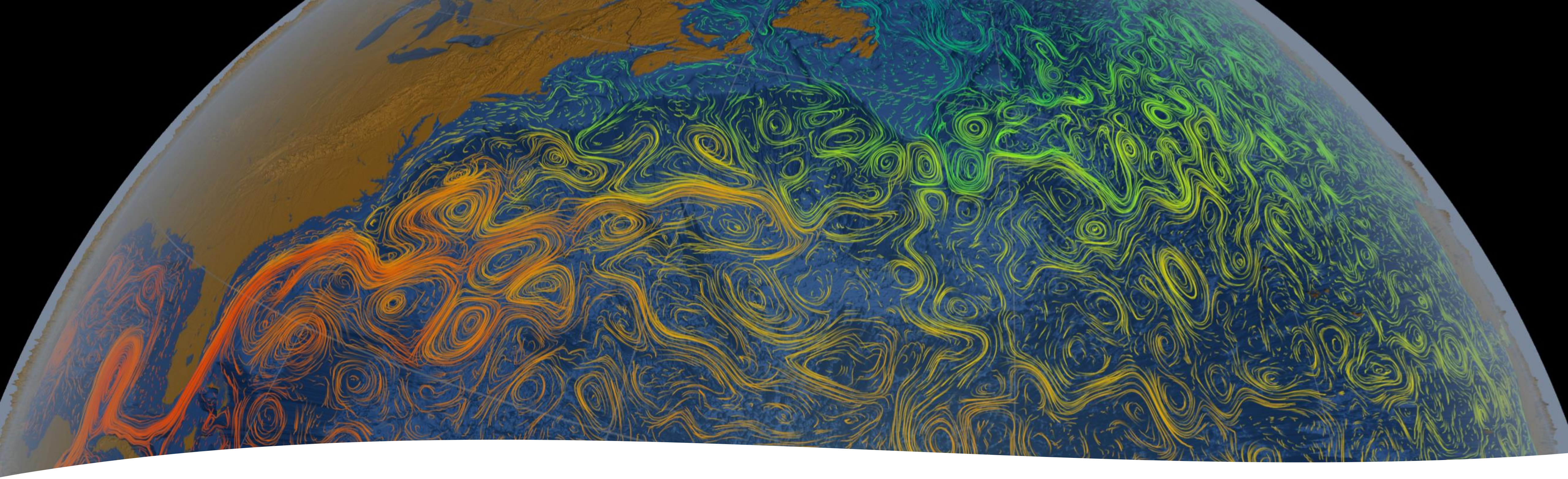
NAFO. 2019. Report of the 12th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). NAFO SCS Doc. 19/25, Serial No. N7027, 135 p.



NAFO EAF Roadmap



KOEN-ALONSO, M., P. PEPIN, M.J. FOGARTY, A. KENNY & E. KENCHINGTON, 2019. The Northwest Atlantic Fisheries Organization Roadmap for the development and implementation of an Ecosystem Approach to Fisheries: structure, state of development, and challenges. *Marine Policy* 100: 342-352.



Unseen but Connected

- Connectivity between closed areas can be realistically modeled by biologically-informed particle tracking analyses that identify, for example:
  - Areas of retention
  - Connected areas
  - Unconnected areas
  - Larval source/sink areas
  - Effectiveness of closed area networks
- Connectivity models can be performed using climate projections and followed up with targeted genetic studies and field collections.