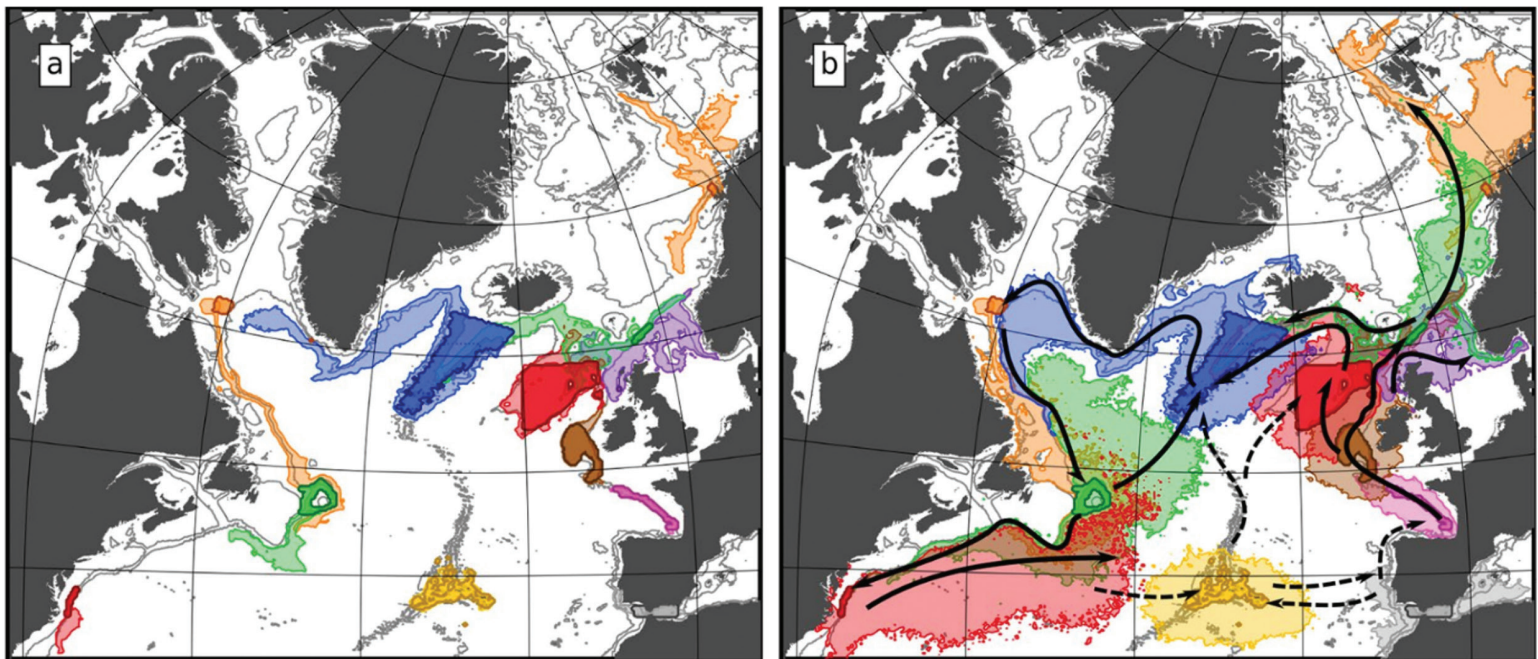


Gaps Analysis Arising from Atlas and iAtlantic Outputs

Recognizing that the main technical role of a transboundary diagnostic analysis (TDA) is to identify, quantify, and set priorities for transboundary environmental problems, and that the SEDA needs to capture experience from other TDA-like processes, this document provides summaries of relevant outputs from other regions targeted for research during the ATLAS (2016–2020) and iAtlantic (2019–2024) European Horizon 2020 programmes on deep-sea and open ocean ecosystems. The aim is to identify gaps in scientific information for the Sargasso Sea Geographical Area of Collaboration that could be of further use and identify any potential existing or future information sources where possible.



A Report Submitted to Sargasso Sea Commission



Gaps Analysis Arising from Atlas and iAtlantic Outputs



A Report Submitted to Sargasso Sea Commission

The Sargasso Sea Commission works to “encourage and facilitate voluntary collaboration toward the conservation of the Sargasso Sea.” The Hamilton Declaration on Collaboration for the Conservation of the Sargasso Sea, established in 2014, provides a framework for voluntary collaboration between ten signatory governments and a Commission of scientific experts operating in their independent capacities for the conservation of the Sargasso Sea.

This work is an underlying report to the Socio-Ecosystem Diagnostic Analysis (SEDA) for the Sargasso Sea—the first analysis of its kind of a high seas ecosystem.

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Further details: The Secretariat of the Sargasso Sea Commission is hosted by the Washington D.C. Office of the International Union for the Conservation of Nature (IUCN), Suite 300, 1630 Connecticut Avenue NW, Washington D.C., 2009, USA.

A full version of this report and of the reports commissioned by the SSC are available for download on the website at www.sargassoseacommission.org

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CHAPTER 6

Environmental Status

6.A Physical Oceanography

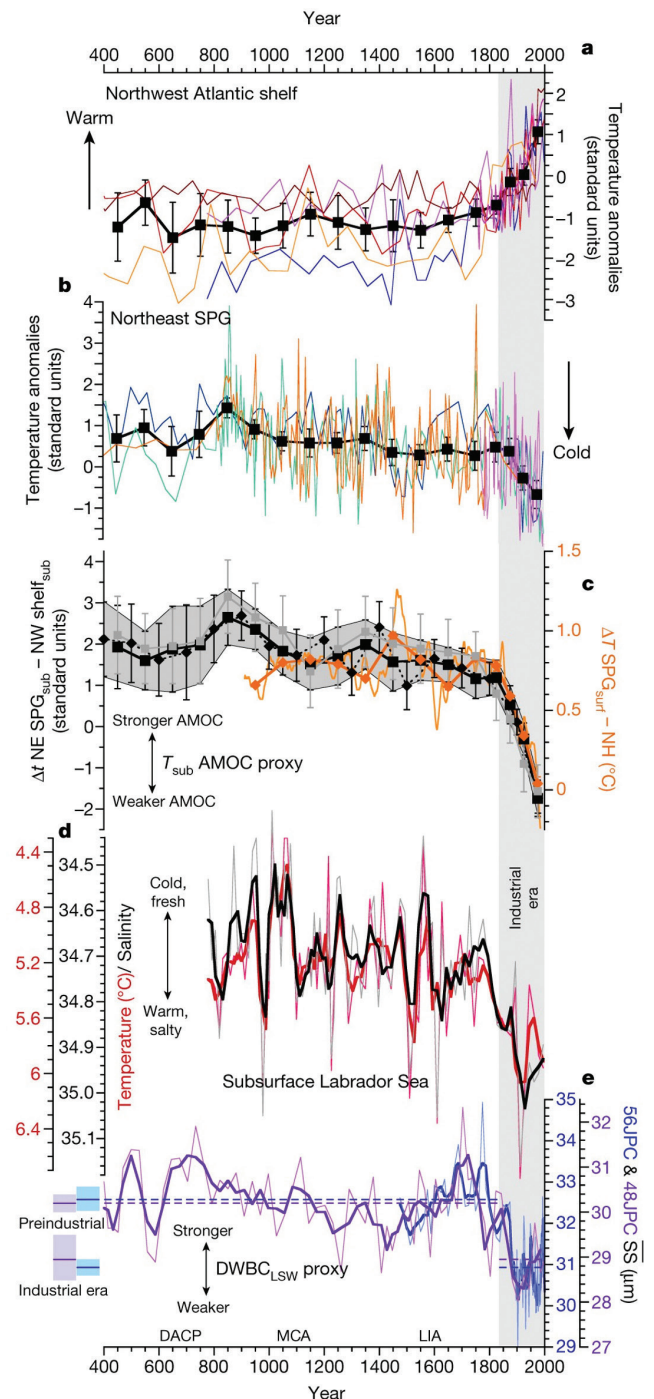
6.A.VII. Gaps analysis

The Atlantic Meridional Overturning Circulation (AMOC) is one of the most important quantities in large-scale oceanography and climate sciences, representing warm northward surface and cold southward deep flows. As a key physical quantify for understanding the impact of the ocean on climate and the evolution of climate change, several oceanographic arrays in the Atlantic are critical to providing scientists with direct observations to monitor the AMOC (Biaostoch et al., 2021). However, spatial and temporal coverage of observational arrays is incomplete; for a Large Marine Ecosystem like the Sargasso Sea, having numerical models that can realistically simulate, hindcast and forecast quantities like AMOC would be very useful to understand horizontal and convective processes and the re-distribution of temperature and salinity in such a large region.

During iAtlantic, the eddy-rich VIKING20X ocean general circulation model was parameterised with different ocean-grid horizontal resolution and atmospheric forcing to see which model could most realistically simulate the AMOC (Biaostoch et al. 2021). The resulting model filled many observational gaps and notably, for the past two decades the simulation experiments suggested that the AMOC in the subtropical North Atlantic has declined by up to 1.5 Sv or possibly less.

It can now be noted that previous ATLAS research reinforced these modelling experiments. Palaeoceanographic and more recent geochemical proxies demonstrating that

FIGURE 1. (Left) From Thornalley et al. (2018), the subsurface Northwest Atlantic shelf (a) and Northeast Atlantic subpolar gyre (b) temperatures, with composite stacks in black. Subsurface temperature AMOC proxy with an AMOC proxy from Rahmstorf et al., 2015 (c). Subsurface temperature and salinity of the northeast Labrador Sea (d). Sortable silt (SS) mean grain size (e). DACP refers to Dark Ages Cold Period, MCA refers to the Mediaeval Climate Anomaly, and LIA refers to the Little Ice Age.



The modelling advances made by Biastoch et al. (2021) during the iAtlantic project can help to simulate recent and forecast changes in this important quantity, which enables users to couple these to long-term monitoring observations in the Sargasso Sea.

Ecological and socioeconomic consequences of AMOC changes in the Sargasso Sea remains a critical knowledge gap.

over the last 150 years the AMOC has been in its weakest state compared with the last 1,500 years (Figure 1; Thornalley et al., 2018).

The research by Thornalley et al. (2018) infers that the AMOC has responded to recent centennial-scale climate change instead of driving it. The consequences of reduced AMOC strength for the environmental and socioeconomic status of the Sargasso Sea are big gaps in our understanding of the Sargasso Sea but recent slowdowns indicate impacts from the surface right down to the deep seafloor ecosystems (O'Brien et al., 2021).

6.B Chemical Oceanography

6.B.VII. Gaps analysis

For deep-sea ecosystems of the Sargasso Sea, *in situ* and *ex situ* experiments, models and observational data on the roles that these systems play in the carbon cycle including secondary production are not well developed. The impacts of single and multiple stressors that deep-sea ecosystems in the Sargasso Sea are experiencing or will experience by the end of the century are vital to understand but yet these are also not known due to a lack of experiments, models and observations on effects of ocean acidification, warming, deoxygenation and anthropogenic contaminants on these systems in the Sargasso Sea.

Deep-sea and open ocean ecosystem function and the impacts of climate change and anthropogenic stressors were core research areas for both ATLAS and iAtlantic programmes and can inform the SEDA's Sections 6.B.IV. (Carbon cycle in the Sargasso Sea; primary and secondary productivity; ocean carbon pump), 6.B.V. (Presence

and impact of anthropogenic CO₂ emissions including ocean acidification, warming and deoxygenation) and 6.B.VI. (Anthropogenic contaminants in the Sargasso Sea). Vulnerable Marine Ecosystems (VMEs) including seamounts were very much a focus of these projects and their outputs can be used for the SEDA's consideration and are therefore highly relevant to the Sargasso Sea with its numerous seamount chains and latest discoveries of even more VME indicator taxa on Bermuda's seamounts (Henry et al., 2024).

Regarding their importance to the carbon cycle and relevant to Section 6.B.IV of the SEDA, hydrodynamic modelling experiments with VMEs on Rockall Bank in Areas Beyond National Jurisdiction and on Condor Seamount off the Azores demonstrated that passive suspension feeders such as cold-water corals can significantly impact the bottom layer of suspended organic matter concentration over large areas of the seafloor, even in regions where their natural biomass is low (Figure 2; van Oevelen et al., 2021).

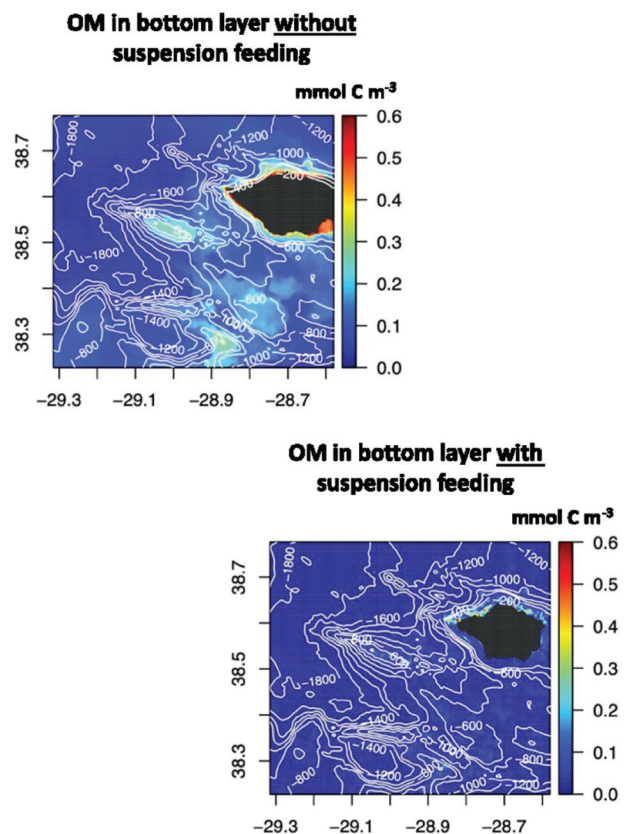


FIGURE 2. From van Oevelen et al. (2021), organic matter concentrations around the bottom of Condor Seamount off the Azores when the biomass of cold-water corals is not coupled (upper panel) versus when it is coupled (lower panel) in these models.

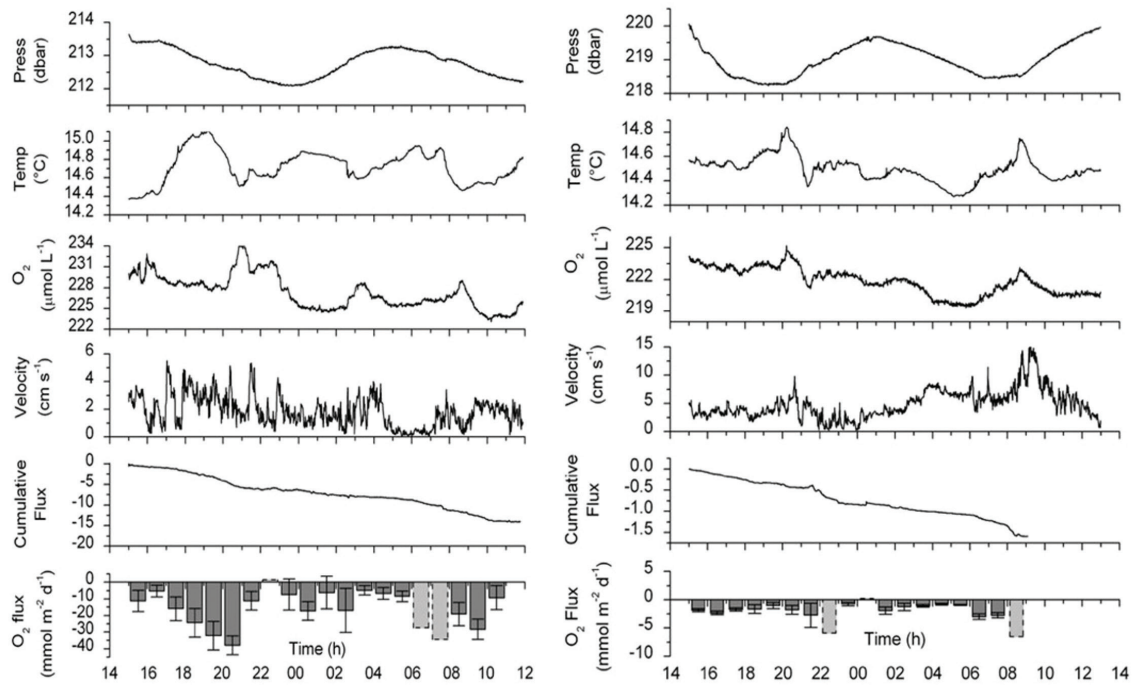


FIGURE 3. From Wolff et al. (2021), an example aquatic eddy covariance (AEC) dataset for a mixed coral garden site (left) and sandy reference site (right) at Condor Seamount. Note the nearly 10 times large rate of O₂ flux in the coral garden site.

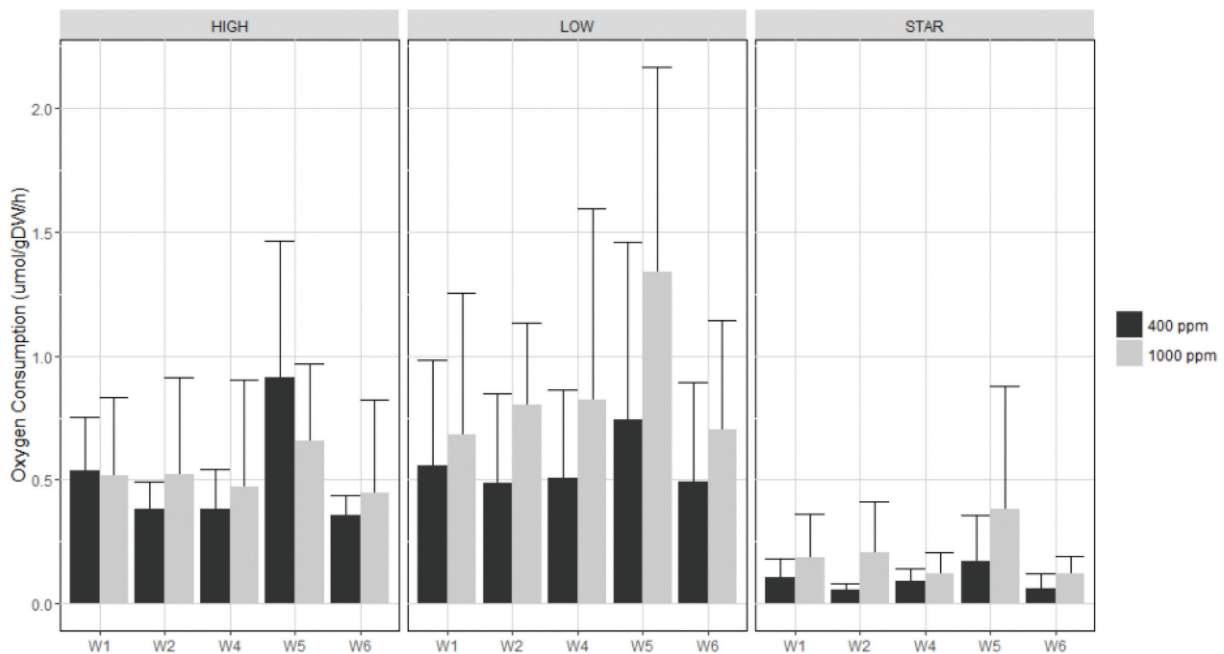


FIGURE 4. From Carreiro-Silva et al. (2021), oxygen consumption by fragments of *Viminella flagellum* under two pCO₂ treatments (control, 400 ppm; high, 1000 ppm) and three food treatments (high food concentration, HIGH; low food concentration, LOW; starved, STAR) for each week.

Data show that the Logachev mound province at the Rockall Bank is a hotspot for remineralisation of organic matter. Two independent methods of determining oxygen utilisation, *in situ* aquatic eddy covariance and *ex situ* incubations, indicated that benthic respiration rates in the vicinity of the scleractinian cold-water corals *Lophelia pertusa* and *Madrepora oculata* are ~5 times higher than those of sediments at comparable depths (Wolff et al., 2020).

At Condor Seamount, octocoral gardens are hotspots for respiration of organic matter when compared to background sediments by a factor of up to ~10 (Figure 3; Wolff et al., 2020).

Ex situ laboratory respiration experiments with live octocorals also suggested that the dominant octocorals *Viminella flagellum* and *Dentomuricea* sp. could contribute ~10% of the total oxygen uptake alone at Condor Seamount's coral gardens (Wolff et al., 2020).

Of relevance to SEDA Section 6.B.V. (Presence and impact of anthropogenic CO₂ emissions including ocean acidification, warming and deoxygenation), *ex situ* aquarium experiments on VME indicator taxa during the ATLAS and iAtlantic projects provided much new information

With the observed and predicted spatial distribution of cold-water corals in the Sargasso Sea suggesting that these deep-sea species commonly occur in the area and potentially in high densities, these kinds of coupled hydrodynamic-biogeochemical models could be used to extrapolate and estimate the larger scale contribution of such species to the carbon cycle in the Sargasso Sea.

and understanding of the impacts of climate change on these species. During ATLAS, *ex situ* experiments conducted over 6 weeks on the octocoral *V. flagellum* demonstrated a significant decline in the mean oxygen consumption under stressful conditions where corals were both lacking in food supply and being exposed to experimental treatments of increased pCO₂ levels (Figure 4; Carreiro-Silva et al., 2021).

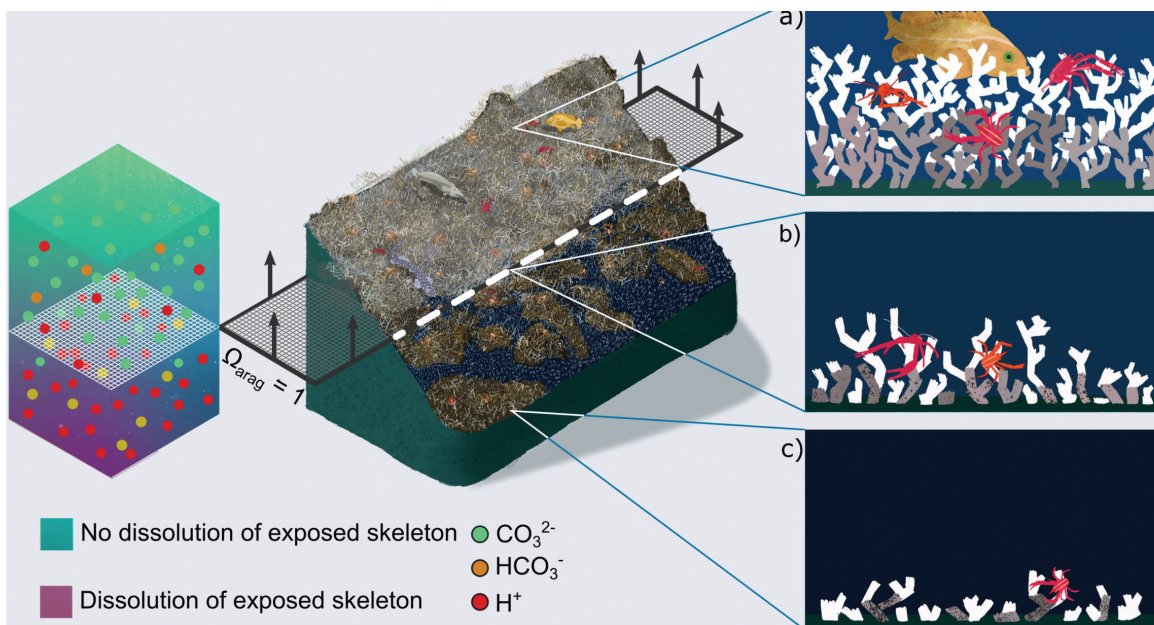


FIGURE 5. From Hennige et al. (2020), a conceptual diagram illustrating cold-water coral habitat loss due to ocean acidification. The panels to the right zoom into areas of present day and future reefs related to the position of the aragonite saturation horizon (ASH), with the aragonite concentration (Ω_{arag}) of 1 or more indicating conditions under which the corals can lay down their skeletons. Panels show a healthy reef with substantial live (white) and dead (grey) coral framework (a), conditions where porosity has started to appear in the dead, exposed skeletal that will lead to the reef framework crumbling, and then finally (c) exposed skeletal framework with much porosity, and which is unable to support complex 3D habitat, although high abundances of live coral can still exist.

Such models of baseline measurements of present-day load-bearing capacity of these corals would allow researchers to investigate timescales of change and to estimate time to reef crumbling. In this way, this approach can support future conservation and management efforts VMEs in the Sargasso Sea.

During ATLAS and iAtlantic projects, a combined *in situ* and *ex situ* approach was used to better understand the risk posed to cold-water coral reef habitats from ocean acidification as a single stressor. This body of work on the ecosystem engineering scleractinian *Lophelia pertusa* lead to the development of a conceptual framework to understand the ecosystem-level impacts from ocean acidification on deep-sea coral ecosystems (Figure 5; Hennige et al., 2020), which can be applied to the reef-framework forming species found in the Sargasso Sea as well.

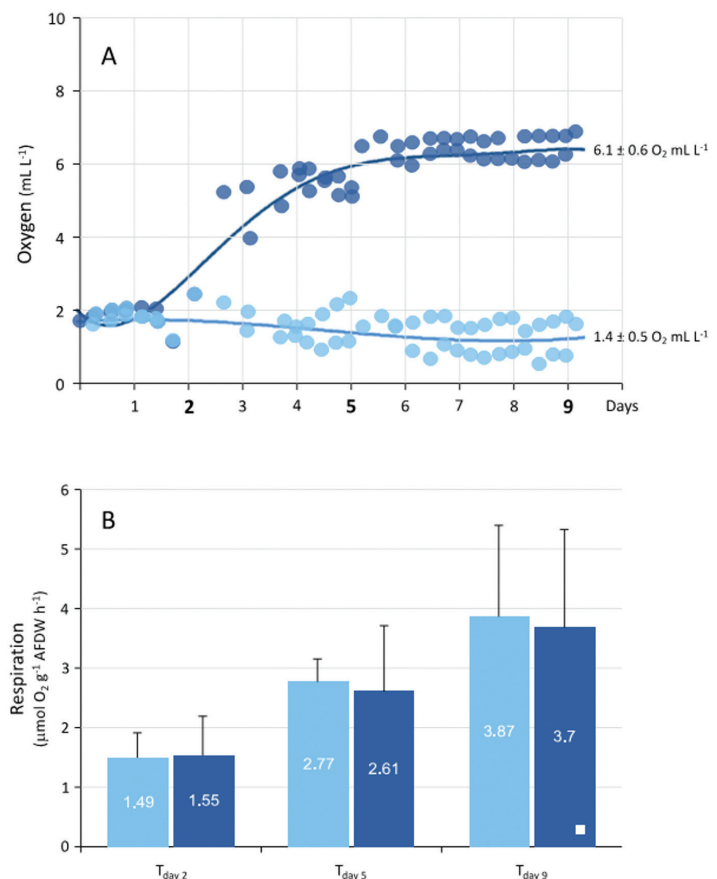
New modelling approaches demonstrate that ocean acidification induces a thinning of the dead coral

framework that supports the living corals on top. This significantly reduces the load-bearing capacity of cold-water corals, which may cause the reef structures to collapse (Wolfram et al., 2022).

In contrast to impacts of ocean acidification both as a single stressor or in combination with reduced food supply, studies conducted during iAtlantic on impacts of deoxygenation on the scleractinian coral *Lophelia pertusa* do not seem to significantly impact respiration in this species and in fact this species can even thrive under such conditions. For example, Gori et al. (2023) used short-term *ex situ* aquarium experiments using coral fragments collected off the Angolan margin to examine the impact of deoxygenation, and detected no significant difference in respiration rates between a low O_2 treatment of $1.4 \pm 0.5 \text{ mL} \cdot \text{L}^{-1}$ and a higher O_2 treatment of $6.1 \pm 0.6 \text{ mL} \cdot \text{L}^{-1}$; Figure 6).

Thus, low oxygen conditions are not a general limiting factor for the overall distribution of this species, and research during iAtlantic even documented another reef framework-forming corals such as *Madrepora oculata* thriving off Angola in extreme hypoxic conditions (Orejas et al. 2021), with the high availability and high quality of

FIGURE 6. From Gori et al. (2023), the top panel (A) shows the time series of oxygen concentrations during the experiments in the low O_2 treatment (light blue) and the increased O_2 treatment (dark blue) treatments. The bottom panel (B) shows coral respiration of under the different treatments over time, which did not significantly vary between treatments.



	Cold-water coral site	Temperature	$\delta^{18}\text{O}_{\text{SW}}$ (Salinity)	Hydrodynamics	Export productivity	Oxygenation
North Atlantic Ocean	Gulf of Mexico (Campeche Bank)					+
	Irish margin (Porcupine Seabight)			+	+	
	Moroccan margin (Gulf of Cádiz)					
	Mauritanian margin					
Mediterranean Sea	Alboran Sea (West Melilla)			+		
	Alboran Sea (East Melilla)			+	+*	

paleoceanographic records: ■ no control ■ control; NRL model: ■ statistically significant control (Dunn-Sidak corrected significance level: + =0.05, +* =0.1)

FIGURE 7. From Porthilo-Ramos et al. (2022), showing environmental variables known to control the occurrence of the *Lophelia pertusa* in the North Atlantic and the Mediterranean Sea over the last 20,000 years. Blue indicates no control, whereas orange indicates the variable is an important controlling force. A regression model was used to identify variables with the most impact on coral development, i.e., triggering the onset or demise of *L. pertusa* proliferation.

food off Angola (e.g., high net primary production of $> 3400 \text{ g C m}^{-2} \text{ day}^{-1}$) thought to counteract potential deleterious effects of hypoxia.

Research during the iAtlantic project continued this thread of evidence, demonstrating the long-term persistence of *L. pertusa* in extreme hypoxic conditions in this region even over glacial-interglacial timescales and despite significant changes in other variables (Matabos et al., 2022). To further scale this research up, an Atlantic-scale basin synthesis of environmental controls on cold-water coral mounds was conducted during the ATLAS and iAtlantic projects, which reinforced the notion that food supply and hydrodynamics have been more important to controlling mound growth over time than other environmental variables (Figure 7; Porthilo-Ramos et al., 2022).

Therefore, research consensus from both ATLAS and iAtlantic projects spanning geological to ecological timescales strongly suggests that multiple stressors including ocean acidification and lack of food impact the distribution and physiological functioning of *L. pertusa* more so than deoxygenation, though it must be noted that species-specific responses to stressors must be further investigated.

Regarding SEDA Section 6.B.VI. (Anthropogenic

Both *L. pertusa* and *M. oculata* occur in the Sargasso Sea but so do other reef framework-forming deep-sea corals such as *Solenosmilia variabilis* and *Enallopsammia rostrata*, and many other species that can form VMEs such as coral gardens, yet responses to multiple stressors on these species are not nearly as well investigated.

Combined threats of both ocean acidification and reduced particulate organic carbon flux to the deep sea are therefore highly likely to similarly impact the cold-water corals of the Sargasso Sea. However, obtaining species-specific responses to these multiple stressors using ex situ and modelling approaches and including palaeoceanographic reconstructions with proxies would be a major step towards understanding the impacts of these threats to the Sargasso Sea.

The reuse of legacy samples could similarly offer a research opportunity for the Sargasso Sea to establish its own baseline for a much larger regional-scale assessment, and with the threat of marine litter and microplastics being actively investigated worldwide, it is important to establish whether future management can improve from this baseline and reduce any possible threats from, e.g., entanglement, ingestion, etc.

contaminants in the Sargasso Sea), the ATLAS project demonstrated the utility of legacy underwater video survey data, benthic samples, and fisheries survey data in establishing baselines on the distribution of marine litter. Re-use of survey data and samples for purposes other than what they were originally intended for adopts the principle of collect once, use many times.

In this way, the ATLAS project was able to re-examine a historic collection of deep-sea benthic samples and process these to isolate fragments of marine plastics and determine the rate of microplastic ingestion in deep-sea benthos to the west of Scotland. A total of 11% of organisms sampled were found to contain microplastics, with fragments subsequently being revealed by Raman spectroscopy to be composed of one of several types of polymers including polypropylene, polyurethane, polystyrene, and polyethylene terephthalate (La Beur et al., 2019). Re-analysis of historic underwater video footage revealed the distribution of various types of marine litter on the deep seabed, including fishing rope, lost lobster pots, fishing nets and tarpaulin (La Beur et al., 2019).

In a separate ATLAS study in ABNJ around the Flemish Pass, García-Alegre et al. (2020) re-examined fisheries data this time to analyse seabed litter data recorded from the EU-Spain groundfish surveys taking place in Northwest Atlantic Fisheries Organization (NAFO) Division 3L between 2006 and 2017. Litter was found in 8.3% of the total trawls, with mean densities of 1.4 ± 0.2 items km^{-2} and 10.6 ± 5.2 kg km^{-2} , and as with off Scotland, this area was dominated by litter originating from fisheries with 61.9% of all litter recorded (García-Alegre et al., 2020).

Returning to the threats posed by multiple stressors, the impacts of climate change in the ocean are occurring

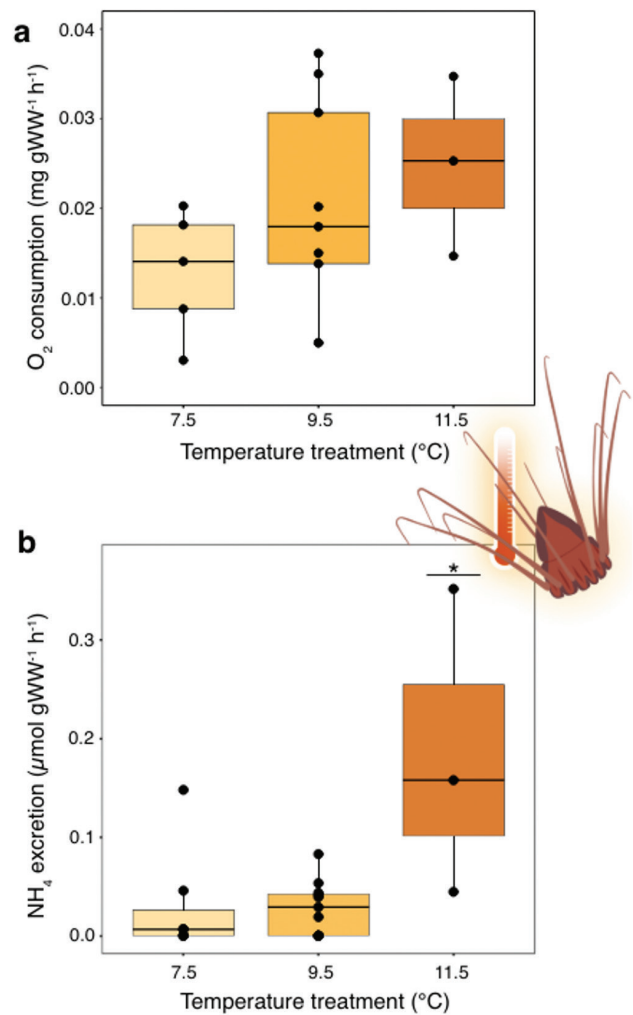


FIGURE 8. From Stenvers et al. (2023), respiration rates (a) and ammonium (NH₄) excretion in the deep-sea jellyfish *Periphylla periphylla* exposed to experimentally elevated seawater temperature treatments.

alongside human activities. Currently, there are no commercial exploitation licenses for deep-sea mining in ABNJ, but the latest research from iAtlantic demonstrated significant impacts to deep pelagic species when the effects of experimental seabed mining were quantified in parallel with effects of ocean warming (Stenvers et al., 2023). This *ex situ* study investigated the effects of simulated ocean warming and sediment plumes on the cosmopolitan deep-sea jellyfish *Periphylla periphylla* that is also common in the Sargasso Sea, and found that metabolic demand increased following a 4°C rise in seawater temperature alongside increased ammonium excretion (Figure 8).

This warming treatment also promoted genes related to innate immunity but which suppressed aerobic respiration.

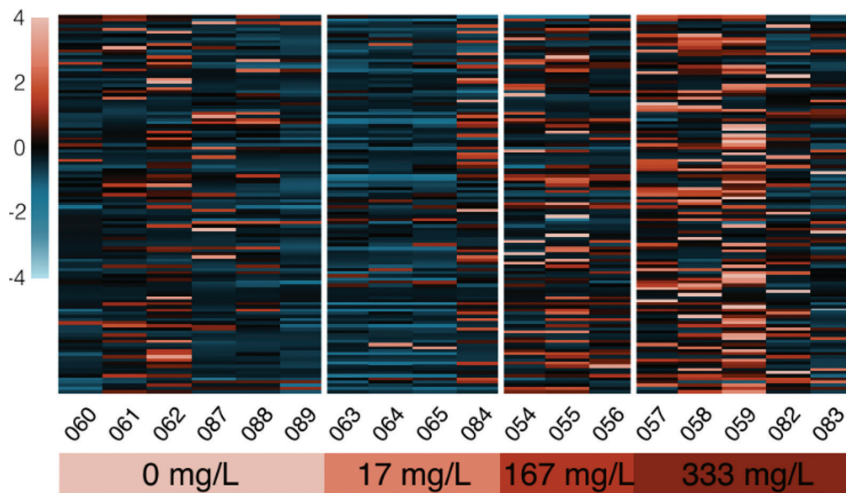


FIGURE 9. From Stenvers et al. (2023), showing a heatmap of 121 genes. Columns indicate sample numbers, and each row represents one gene. Colours indicating expression values, where blue indicates below-average expression, with yellow to red indicating above-average expression.

The suspended sediment plumes provoked an acute and energetically costly response through the production of excess mucus, while inducing genes related to aerobic respiration and wound repair (Figure 9; Stenvers et al. 2023).

Notably, if mining does occur in future in the Sargasso Sea and plumes are present in the water column for an extended period of time, then any increase in metabolism will either require increased food intake or sustained mucus production, the latter which will exhaust the organism, leading to energetic depletion and threaten its survival. If one considers these responses to be representative of what can happen in other gelatinous species, then impacts of any future exploitation in the Sargasso Sea could significantly impair the deep pelagic biodiversity and ecosystem functioning in this Large Marine Ecosystem, as noted by Stenvers et al. (2023).

The combined experimental biology and genomics approach used here could be extrapolated to the Sargasso Sea with future targeted collections to establish baselines in the deep pelagic realm, combining physiological and gene expression approaches, which can even help to detect systems that may currently be under stress, e.g., by scanning for over-expressed genes.

CHAPTER 8

Other Major Impacts on the Ecosystem

8.A. Climate Change

8.A.I. Gaps analysis

During the ATLAS project, Levin et al. (2020) proposed a suite of approaches to enable marine managers to incorporate climate change into their practices. Levin et al. (2020) considered several ways in which, and therefore several reasons why, climate change will impact the deep seafloor and why managers need to integrate it into their decision-making. Their reasons include the rapid pace of environmental change on the seafloor due to climate change, that climate change impacts the recovery potential of deep-sea ecosystems, and how resource extraction can impact carbon cycling. It is therefore highly relevant for the SEDA to consider this reasoning in the context of the Sargasso Sea, despite some large knowledge gaps in the nature and pace of these changes in the near future.

Some of these data gaps can be approached using the ocean-climate change forecast models developed during the ATLAS project by Sweetman et al. (2017). These outputs can help to identify which variables will likely change by 2100 in the Sargasso Sea, and by how much. To derive the future ocean projections seen in Figure 10, Sweetman

et al. (2017) compiled data generated by 31 Earth Systems Models as part of the Coupled Model Inter-comparison Project Phase 5 (CMIP5) to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, as in Mora et al. (2013). Multi-model averages of temperature, pH, O_2 and particulate organic carbon (POC) flux to the seafloor were reported as interannual mean projections between 2090 and 2100.

From these model estimates, the deep seafloor of the Sargasso Sea appears largely not to change significantly in terms of dissolved oxygen or pH (Figure 10) but there is slight reduction in POC flux to the seafloor (Figure 10) by 2100 relative to present day conditions. Changes in POC flux and food supply can significantly impact VMEs and their ability to withstand stressors, e.g., the ATLAS case study of the octocoral *Viminella flagellum* around the Azores being able to tolerate reduced pH if food supply was still adequate (Carreiro-Silva et al., 2021), or the iAtlantic study region around Angola demonstrating the long-term resilience of *Lophelia pertusa* in extreme hypoxic conditions likely due to a sustained high quality food supply with amenable hydrodynamic conditions (Porthilo-Ramos et al., 2022).

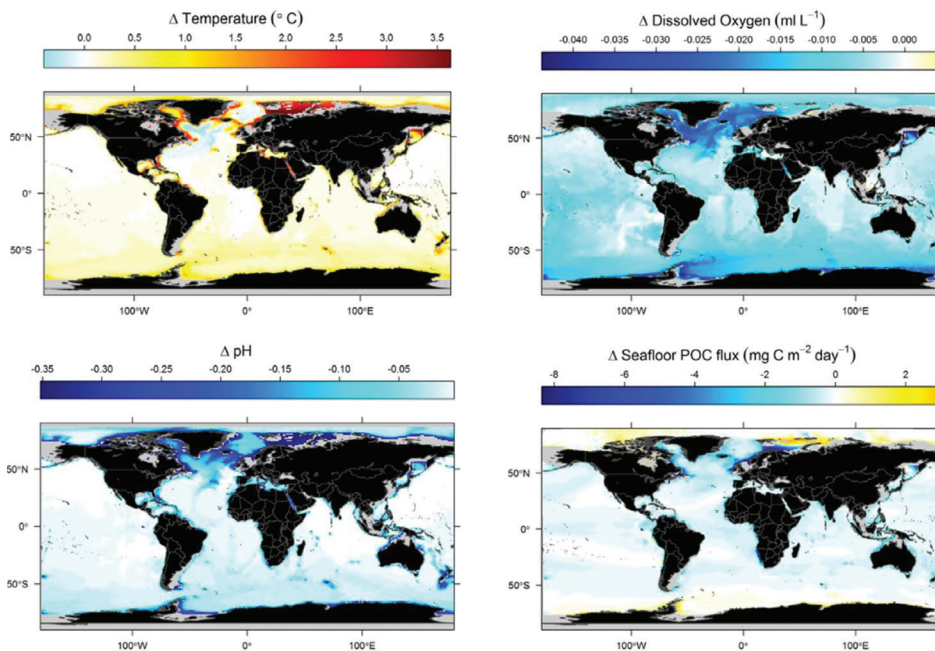


FIGURE 10. From Sweetman et al. (2017), showing changes in deep seafloor temperature ($^{\circ}\text{C}$), dissolved oxygen concentration (mL L^{-1}), pH, and seafloor POC flux ($\text{mg C m}^{-2} \text{d}^{-1}$) predicted by 2100 relative to present day conditions.

The pH of the bottom waters in the Sargasso Sea do not seem to change substantially between the present day to 2100, but many VME indicator taxa in this Large Marine Ecosystem occur in intermediate depth layers where declining pH could pose issues to calcifying organisms such as scleractinian corals and therefore the future carbonate chemistry of the intermediate waters needs to be better understood, as do the responses of VME indicator taxa in this region.

Also notable from Figure 10 is that the northern Sargasso Sea appears to get slightly cooler while the southern half of the Sargasso Sea appears to get warmer. The forecasts to 2070 conducted by the iAtlantic project (Burmeister et al., 2022) predicted cooler water temperatures in the bottom layers surrounding Bermuda's BATS station, which would also broadly be consistent with the findings by Sweetman et al. (2017), as it lies relatively closer to Bermuda and not in the southern half of the Sargasso Sea.

Returning back to the intermediate and surface waters, there was much consensus across the iAtlantic project that warming seawater temperatures have in the past driven significant changes in ecosystems around the Atlantic Ocean. Many studies conducted during this project identified a significant "tropicalization" of deep and open ocean fauna across the Atlantic Ocean basin (Matabos et al., 2022).

In iAtlantic, this critical driver of change was best exemplified in the South Atlantic. Like the Sargasso Sea where there may be a lack of annual surveys across the whole area, at first it appeared there were also few long-term ecosystem time series to analyse the effects of rising seawater temperature changes over an area as large as the South Atlantic. iAtlantic researchers overcame this by capitalising on long-standing collaborations built up over years to make use of the fisheries-dependent industry data from the International Commission for the Conservation of Atlantic Tunas (ICCAT). These data were then coupled back to iAtlantic's hindcasts using the INALT20 model (Schwarzkopf et al., 2019). In this SEDA report, the methods are briefly presented to illustrate an approach that can in future be used to assess similar

trends and impacts of a warming surface ocean in the Sargasso Sea GAC.

To spatially constrain the analysis across such a large area, iAtlantic researchers divided the South Atlantic into South West Atlantic Ocean (SWAO) and South East Atlantic Ocean (SEAO) divisions, based on general population divisions used by ICCAT (Figure 11). Annual catches in biomass from ICCAT were compiled for each division, and analysed separately (see full methods description in Matabos et al., 2022). An overall mean temperature preference value was calculated across the 29 species representing the top 95% of caught biomass, which included many species found in the Sargasso Sea as well. Some of the dominant species included tuna (e.g. *Thunnus thynnus*, *Thunnus alalunga*, *Thunnus obesus*, *Thunnus albacares*, *Katsuwonus pelamis*, *Auxis thazard*, *Thunnus atlanticus*, *Auxis rochei*, *Euthynnus alleteratus*), billfish (e.g. *Makaira nigricans*, *Istiophorus albicans*, *Tetrapturus pfluegeri*, *Kajikia albida*, *Xiphias gladius*) and pelagic sharks (*Prionace glauca*, *Lamna nasus*, *Isurus oxyrinchus*). The overall mean temperature preference value was then used to assign warm- or cold-water affinities for species whose thermal preferences were above or below this value, respectively. Thus, the "mean temperature of the catch" (MTC) could be estimated for each year (y), *sensu* Cheung et al. (2013). To quantify the impacts of warming oceans on the MTC, sea surface temperature (SST) was derived from estimates provided by the INALT20 model (Schwarzkopf et al., 2019) for hindcasts spanning from 1978 to 2018 calculated by averaging the temperatures over 0.25° x 0.25° grid cells of the South Atlantic Ocean and a water column between surface and 10 m depth. Annual values of both MTC and SST were normalized by their mean value over the time series, and expressed as anomalies.

Linear regression modelling showed SST to have significantly and positively affected MTC in both divisions, with MTC clearly increasing over time due to an increase in catches of species with more warm-water affinities and the loss of species with cooler water affinities. These

For the Sargasso Sea where iAtlantic has forecasted significant increases in temperature by 2070 in these more intermediate to surface layers, there is therefore an urgent need to assess the role temperature plays in driving ecosystem change in the Large Marine Ecosystem.

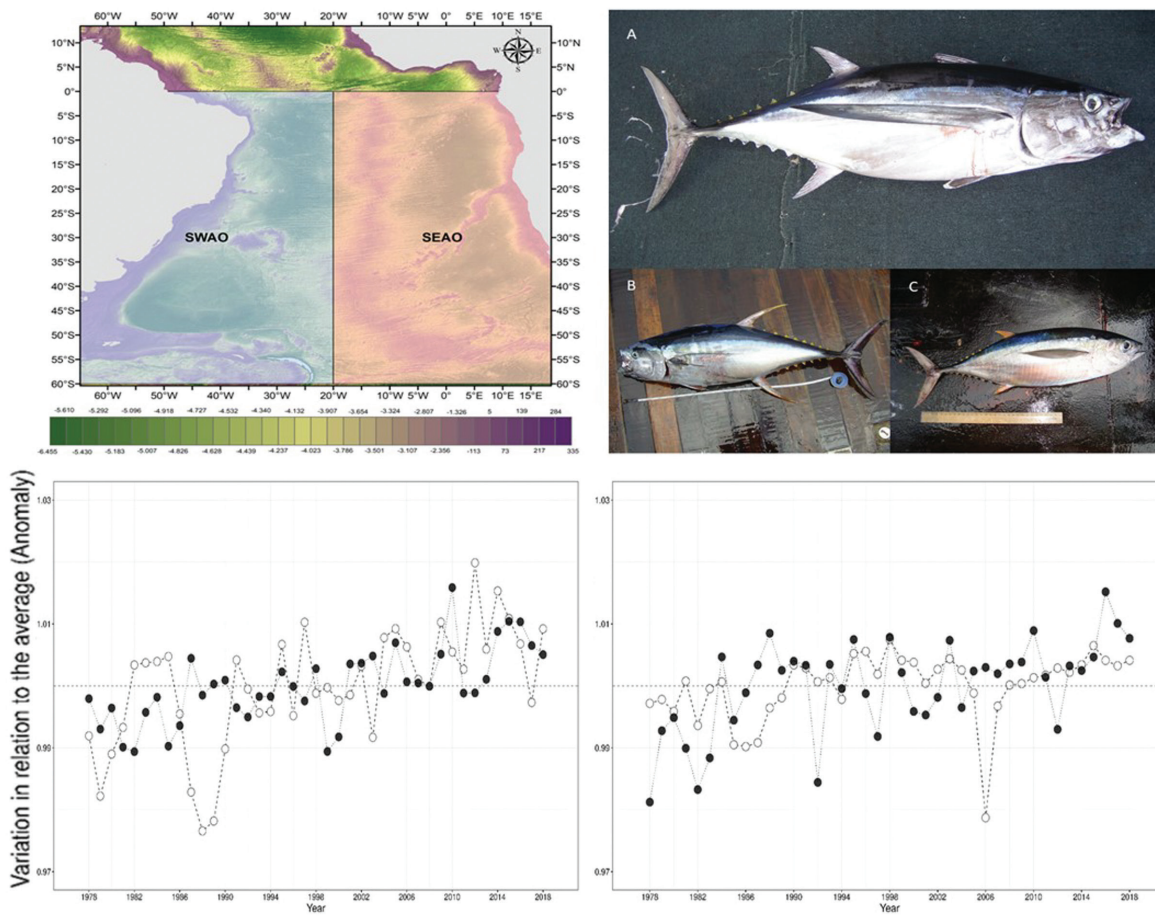


FIGURE 11. From Matabos et al. (2022), showing how the mean water temperature of the catch (MTC) caught by fleets operating in the ICCAT management area in the South Atlantic has changed since 1978 to 2018. Counterclockwise from top left: top left panel shows the division of the South Atlantic; bottom left and right panels show the annual variability of the MTC (white dots) of the pelagic fisheries monitored by ICCAT with the annual mean SST (black dots), showing close tracking of the MTC with ocean temperatures; top right panel showing some of the main species that illustrate the “tropicalisation” of species targeted by both the South Atlantic commercial and sport-fishing industry where catches of albacore (A) have been increasingly replaced by more catch of yellowfin tuna (B) and big eye tuna (C), tuna Images courtesy Roberto Bavares and Dimas Gianuca.

changes are closely associated with the INALT20 model-derived SST trend, but when these changes occurred seem to differ (after 2002 in the southwest and since the 1990s in the southeast). Mechanistic explanations for SST also differ, for example the southwest Atlantic division has been affected by the wind-induced poleward expansion of the Brazil Current warm waters and the associated confluence with the cold-water Malvinas Current, whereas in the southeast these changes were thought to perhaps be associated with the weakening of alongshore southerly winds and reduced coastal upwelling and the gradual southward expansion of well-stratified tropical waters (Roch et al., 2021).

Of note for the Sargasso Sea is that iAtlantic findings in the South Atlantic Ocean corroborate evidence world-wide for the tropicalization of large pelagic fish including

Applying the MTC index to ICCAT data constrained to the Sargasso Sea or the western and northwest Atlantic Ocean in general could help to overcome data gaps on decadal changes relating to ocean warming as it has been done in other Large Marine Ecosystems.

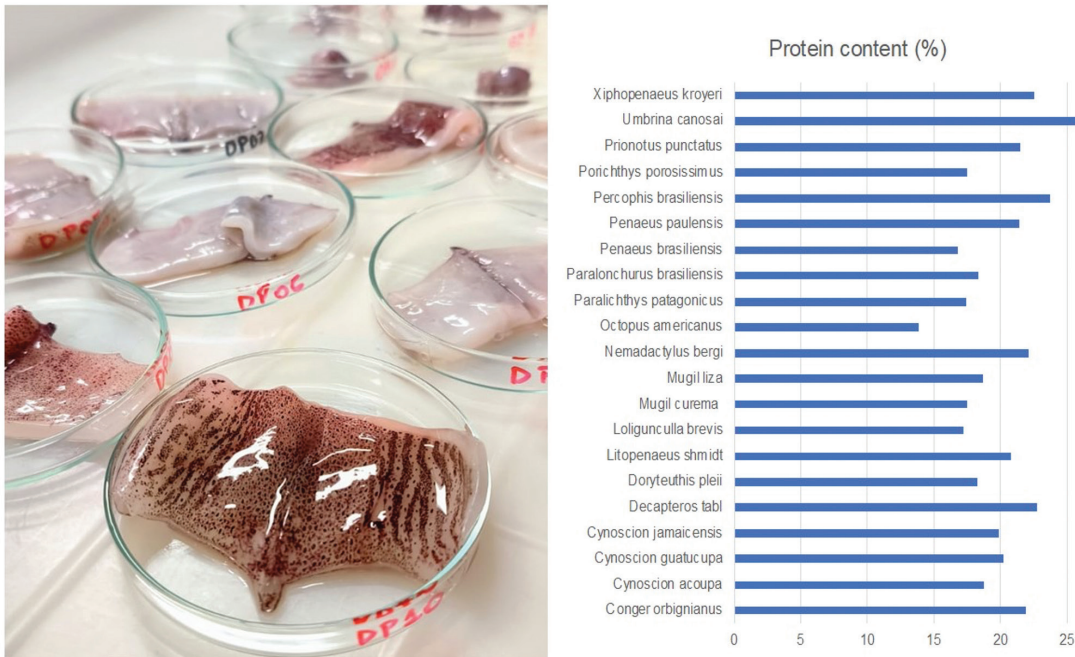


FIGURE 12. Unpublished data from Tha and Perez, showing the nutritional analysis of protein content in 32 of the most commonly caught demersal fish species.

those described in many Large Marine Ecosystems (Cheung et al., 2013). In the iAtlantic project, the MTC index was also applied to study impacts of SST on the demersal fisheries catches in the South Brazil Large Marine Ecosystem as well, with similar striking results illustrating a “tropicalization” of the demersal fisheries here too (Perez and Sant’Ana, 2022).

Emerging results from the iAtlantic project are also now demonstrating the socioeconomic consequences of this tropicalization, with an overall reduction in the protein content of the landed demersal catches going to market (Figure 12).

Overall, the quantity of protein offered by the demersal catch of southern Brazil was shown to drop by 9%, while the landing value of the catch, however, increased slightly by 2%, due to the rising shares in shrimps.

Besides Large Marine Ecosystems, the MTC index has also been applied in smaller regions for demersal and pelagic fisheries including the Aegean and Ionian Seas (Tsikliras et al., 2015), the Yellow and East China Seas (Liang et al., 2018) and the Bay of Biscay (Punzón et al., 2021). Thus, the use of the MTC as an index could be extended to the Sargasso Sea to analyse impacts of climate change on pelagic fisheries and thus ecosystem services provided by the Sargasso Sea Large Marine Ecosystem using ICCAT data in a similar approach to the one used by these studies and in the iAtlantic project.

Analysing the nutritional and economic value of catches gives a new perspective on the socioeconomic consequences of these tropicalization phenomena and would be an important gap for future studies in the Sargasso Sea GAC to fill. These findings are also of direct relevance to the SEDA Section 9 on Ecosystem Valuation and Cost Benefit Analysis.

CHAPTER 9

Ecosystem Valuation and Cost Benefit Analysis

Improved knowledge of the values provided by seafloor ecosystem services will help to develop policy action, development of Marine Protected Areas and other area-based management tools in the Sargasso Sea GAC. This new knowledge could also help design responses to global change that will impact deep-sea ecosystems and the services they provide. During the ATLAS project, new information was collected, synthesised and analysed that started to put in place the approaches and information required for economic baselines to aid decision-making (Tinch et al., 2021b). Relevant to the Sargasso Sea Large Marine Ecosystem where this could be replicated to fill in any gaps, this aspect of the ATLAS research programme took an inventory of deep-sea ecosystem goods and services in all 10 case study regions (Foley et al., 2018), it assessed risks to ecosystem services from diverse human drivers and climate change (Armstrong et al., 2017b, 2019b), it collected stated-preference valuation surveys for two ATLAS case study areas (Ankamah-Yeboah et al., 2021, 2022), and conducted a Q study of decision-makers' and stakeholders' views on the legitimacy, validity and acceptability of monetary valuation methods and the use of values in decision support (Tinch et al., 2021a). For the purposes of the SEDA, several of these approaches are outlined below to assist in filling in any gaps to perform ecosystem valuations and cost benefit analyses for the Sargasso Sea GAC.

During ATLAS, Armstrong et al. (2017a) developed bioeconomic models on a case study of cold-water corals and northeast Atlantic cod around Norway. This research demonstrated that there is a willingness to pay (WTP) to protect even the relatively unknown resources in the ocean such as those in the deep sea, not just due to the charismatic nature of the resources here but also for reasons specifically related to their importance for the very existence of fish. This indicates the need for economic assessments to include more non-use values in marine ecosystems. Armstrong et al. (2017a) also noted the risks that regime shifts pose to management practices, and how to achieve optimal management of both the fisheries and the habitats that support them.

Advancing this concept of WTP further, Arm-

Relevant for the Sargasso Sea, setting attributes according to what a Strategic Action Plan (SAP) calls for would be a good way to capture the public's and other stakeholders' views on their WTP for conservation action balanced with economic development.

Offering the public and stakeholders opportunities to take part in discrete choice experiments regarding management scenarios or possible actions being proposed by the SAP would provide a more participatory approach to ocean governance of the Sargasso Sea system.

strong et al. (2019b) used discrete choice experiments in Norway and Ireland to assess the public's willingness to trade-off between industry exploitation (in this case, oil and gas production and fisheries exploitation) and marine conservation (in this case, the protection of cold-water coral habitat). The choice experiment asked respondents to choose between three alternatives for habitat protection (two with increased habitat protection and 1 being the status quo), with each alternative being characterised by four attributes (the size of coral habitat area protected, importance to industry, importance of the habitat for fish, and an estimate of the additional cost to protect that area of habitat). Although not directly comparable to the full range of economic activities in the Sargasso Sea, the choice experiment approach demonstrated two findings that could assist the SEDA in understanding how to approach cost and benefits now and in the future. First, Armstrong et al. (2019b) found that the public from both nations expressed a clear WTP to conserve cold-water coral in the deep sea provided that the corals are providing fish habitat. Second, the researchers found that the public expressed strong endorsement of ecological considerations in decision-making, whereby preferences

between different management scenarios was afforded more to the role of cold-water coral in supporting the well-being of fish, which they interpreted as a WTP for the existence value of fish, even if it involved restrictions on resource extraction in the form of no-take zones (Armstrong et al., 2019b).

The ATLAS project rolled out the discrete choice experiment approach to Norway and Scotland next (Ankamah-Yeboah et al., 2021, 2022), only this time

the attributes mapped directly onto management goals and indicators outlined by the European Union's Marine Strategy Framework Directive (MSFD). Despite significant variations in WTP, the public generally did not favour the current status quo management scenario (Ankamah-Yeboah et al., 2021, 2022), with another ATLAS study showing that only 22% and 33% of Norwegians and Scots, respectively, think their deep-sea area areas are well-managed (Ankamah-Yeboah et al., 2020).

CHAPTER 10

Connectivity Within and Beyond ABNJ System Boundary

The ATLAS and iAtlantic projects adopted and then innovated on biophysical models and genomic seascape approaches to improve concepts and ground-truthed understanding about the cross-boundary connectivity in study areas across the Atlantic Ocean, which could assist the SEDA in identifying gaps in knowledge or address them in future. Most of these studies targeted connectivity in Vulnerable Marine Ecosystem (VME) indicator taxa such as cold-water corals, sponges and hydrothermal vent mussels, as these were of direct management and conservation interest. With the climate emergency and uncertainty around impacts to deep-sea and open ocean ecosystems, some of these studies built in elements of understanding how different ocean circulation regimes and ocean states might affect cross-boundary connectivity as well.

ATLAS research using simulated ocean environments to release “virtual” dispersive larvae made several important discoveries that can be considered in the SEDA. First, these simulations found that vertical swimming behaviours of simulated larvae can have an order of magnitude impact on dispersal (Fox et al., 2019; Gary et al., 2020).

Biophysical models offer a strong approach to estimate possible cross-boundary connectivity within and beyond the Sargasso Sea.

For VMEs in the Sargasso Sea, this underscores the importance of biological studies on at least some of the more common VME taxa where possible if MPA networks to conserve these features are of interest in any kind of action plan.

This can be illustrated by comparing how far larvae may spread depending on whether they are at the seafloor and no longer swim or have limited to no swimming ability, versus when larvae are at the surface perhaps due to having swimming speeds that allow them to reach shallower waters from deeper depths where they were initially released (Figure 13).

Thus, the Gary et al. (2020) study concludes that

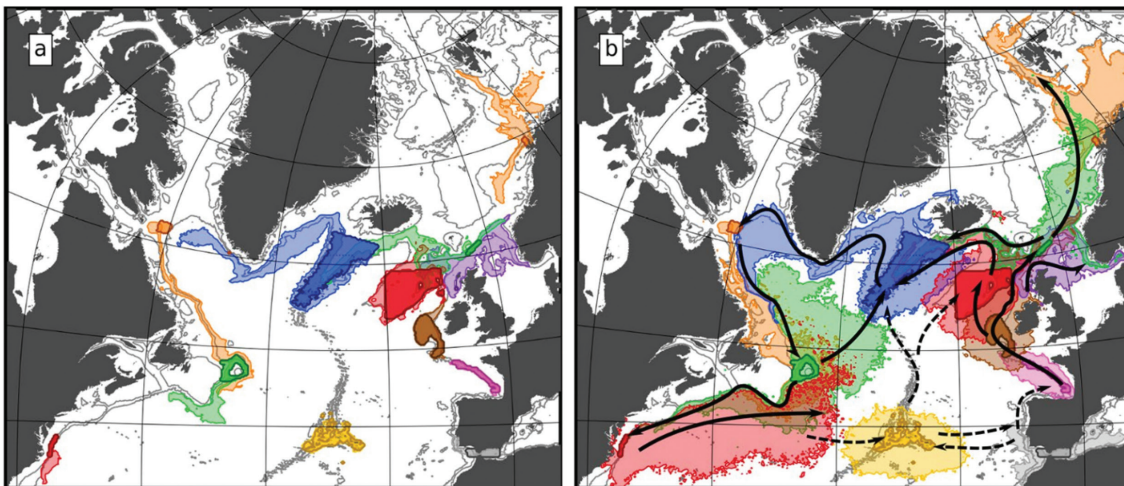


FIGURE 13. From Gary et al. (2020), contrasting how far the densest 95% of modelled particles (larvae) disperse after 185 days based on whether they were released closest to the seafloor (a) or closest to the surface (b). The different coloured regions indicate the 10 ATLAS Case Study areas where generic larvae particles were released in a simulated environment, with the surrounding lighter regions of matching colour showing the extent of their spread. Note, the black arrows in (b) show predicted major pathways of connectivity with dashed arrows showing more uncertain connectivity pathways.

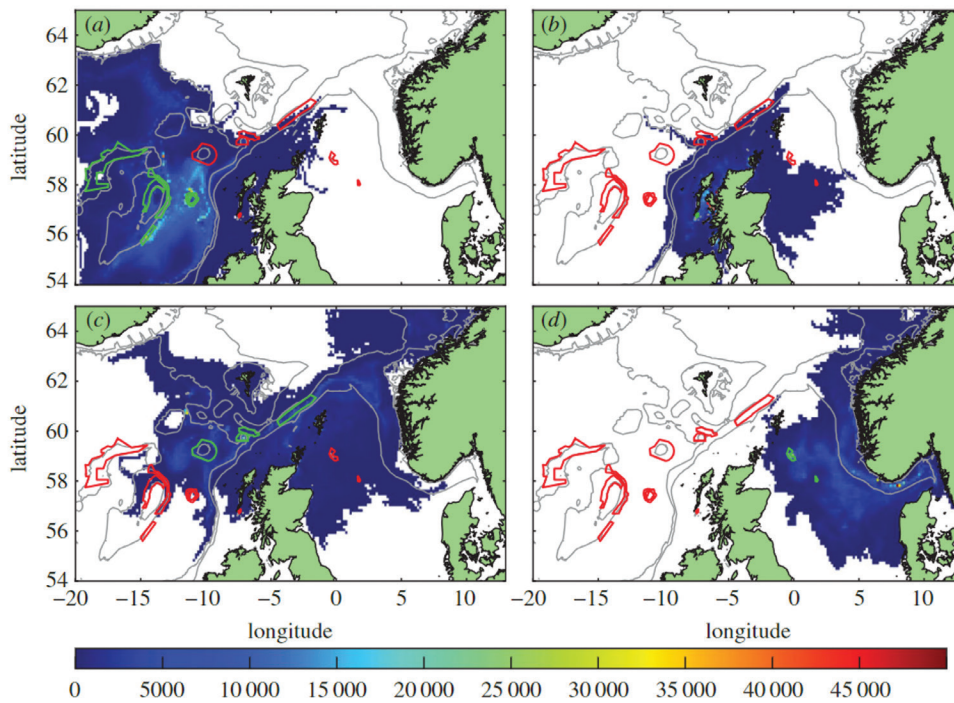


FIGURE 14. From Fox et al. (2016), showing the spreading of competent coral larvae ready to settle in a scenario with larvae having a long lifespan. Polygons in green outline are the source MPAs where larvae were “released” in a simulated environment including a series of (a) western MPAs, (b) the East Mingulay MPA, (c) northern MPAs, and (d) North Sea MPAs. The colour ramp represents the number of larval days recorded in a given model grid square.

data gaps on larval behaviour traits will seriously impede models of deep-sea ecosystem connectivity, and limit the ability to develop ecologically coherent marine protected area networks in a transboundary context.

What can also be gleaned from this output (Figure 13b specifically) is that for those VME taxa (or for any marine taxa) with larvae that do reach surface or near-surface waters off North Carolina in the USA and off the Flemish Cap in ABNJ just outside of the Canadian Exclusive Economic Zone, there is a good probability that some larvae will disperse into and therefore be connected to the Sargasso Sea.

During ATLAS, Fox et al. (2016) modelled the sensitivity of a cold-water coral marine protected area (MPA) network in the United Kingdom to changes in ocean circulation patterns, in accordance with variation in the dominant mode of physical variability in the North Atlantic, the North Atlantic Oscillation. Two key findings were noted: first, significant variability in MPA network connectivity was observed and strongly correlated to changes in NAO, which affects the directionality of ocean currents in the region (Figure 14).

The second key finding and relevant to the Sargasso Sea and connectivity to national jurisdictions, was related to the first key finding: connectivity between MPAs in UK waters and ABNJ was highest during the negative NAO state. This state would have been associated with less strong westward winds, and a westward retraction of the

Thus, in addition to filling in data gaps on life history traits in VME and other deep-sea and open ocean species in the Sargasso Sea, acquiring a better understanding of cross-boundary connectivity using these frameworks will also need to consider different climate states and the roles that dominant modes of physical forcing can play in the transport of ocean currents across this Large Marine Ecosystem.

subpolar gyre and associated currents flowing from east to west (Fox et al., 2016).

Building on the biophysical modelling approaches, more than 5Tb of genomic data were obtained during iAtlantic to study the genetic variations of 10 species or species complexes including cold-water corals, vent and seep molluscs and vent shrimps on a genome-wide basin scale. Some key findings relevant to the Sargasso Sea in the absence of genetic data for most deep-sea species and especially VME indicator taxa in this large region is that there is strong evidence for some taxa being genetically isolated, e.g., the hydrothermal vent species along the Mid-Atlantic Ridge (Jolliet et al., 2024). For genetically isolated units, these would therefore need to be managed

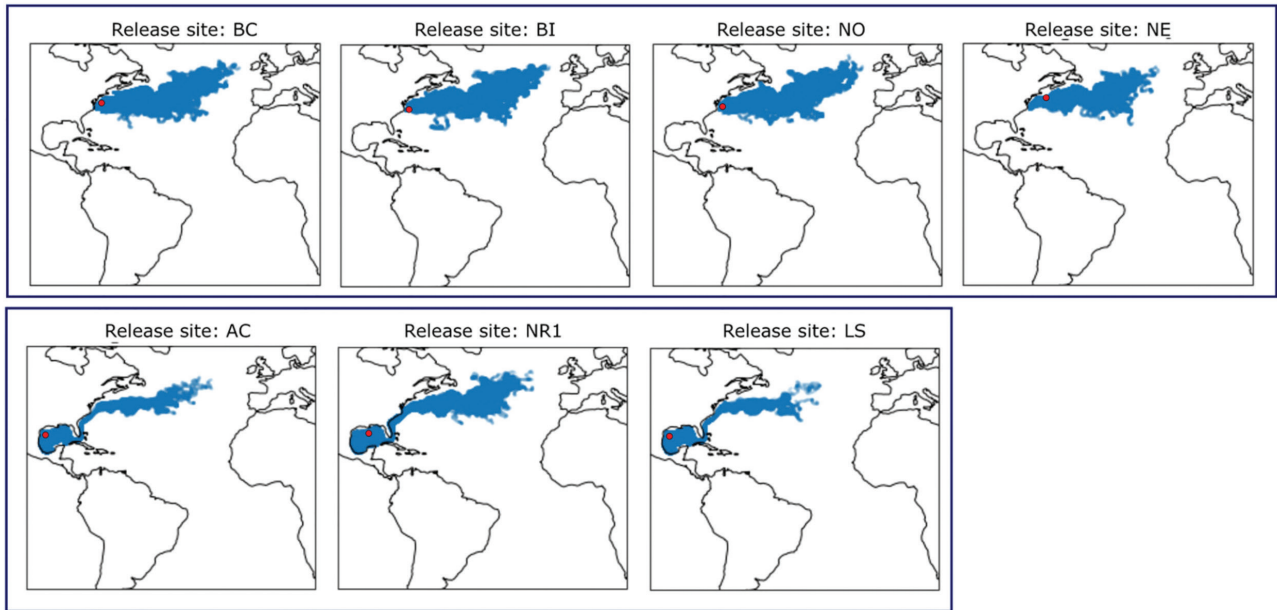


FIGURE 15. From Portanier et al. (2023), showing simulated larval distribution and trajectories (blue tracks) of cold seep mussel larvae after one year after releasing from four seep localities (red dots) along the eastern US margin (top panel) and three release localities in the Gulf of Mexico (bottom panel).

individually, taking into account the genetic information obtained at a regional scale.

In contrast to the hydrothermal vent fauna, genomic data and biophysical models of Atlantic cold seep mussels ground-truthed cross-boundary connections. Notably for the SEDA, the biophysical modelling performed during iAtlantic by Portanier et al. (2023) showed likely dispersal pathways originating from the Gulf of Mexico, through the Florida Strait, and northward along the US margin and then heading eastward into the Mid-Atlantic Bight and into the Sargasso Sea though notably genomics did identify a genetically isolated population on the Blake Ridge (Figure 15, Portanier et al., 2023). Similarly, larvae released from the US Atlantic margin dispersed northwards towards Nova Scotia passing through the Sargasso Sea, and then eastward across the North Atlantic (Figure 15, Portanier et al., 2023).

Genetic validation of these modelled biophysical connections linking VME indicator taxa of conservation and management interest in the Sargasso Sea to other regions is needed to validate predictions.

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