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UNDERSTANDING DEEP ATLANTIC ECOSYSTEMS

iAtlantic
INTEGRATED ASSESSMENT OF ATLANTIC MARINE ECOSYSTEMS IN SPACE AND TIME

POLICY BRIEF

Changing ocean state and its impact on natural capital

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Executive Summary

- Ocean circulation is a dominant controller of the locations and abundances of important marine ecosystem resources.
- Changing circulation has already led to political disputes among the UK, Iceland, Norway, the EU and Greenland.
- These changes are likely to continue.
- Climate models do not capture the full range of variability in the North-East Atlantic, so continued observations and improved biological understanding are both needed to assess oceanographic change and its ecological implications.

Daniel Sorm / unsplash

Ocean circulation plays a fundamental role in governing marine resources. It exhibits cycles that last decades and is likely to be strongly influenced by climate change. This policy brief outlines new knowledge gained as part of the ATLAS and iAtlantic projects on the changing Atlantic Ocean circulation and its impacts on marine natural capital. It highlights the need for sustained in-situ observing and enhanced biological understanding to improve future forecasts of ecosystem response.

Background

The marine (blue) economy of the UK is estimated to be £192 billion (2014)[1]. £5.7 billion is directly related to fisheries and aquaculture. Other benefits provided by the ocean include significant absorption of heat[2] and anthropogenic carbon dioxide[3,4]. The UK is currently in the process of negotiating with the EU to determine policies towards fisheries following the UK's exit from the European Union. In addition, the government must take into account growing industries such as marine renewables[5] and deep-sea mining, and commitments to achieve good environmental status of UK seas, including completing the current network of marine protected areas[6].

A robust maritime spatial planning approach capable of considering these issues is complicated by the uncertain implications of altered ocean circulation, which are themselves subject to climate change. The UK is a world leader in sustained ocean observing and marine ecosystem research, providing critical new understanding into how marine natural capital will be affected by our changing seas.

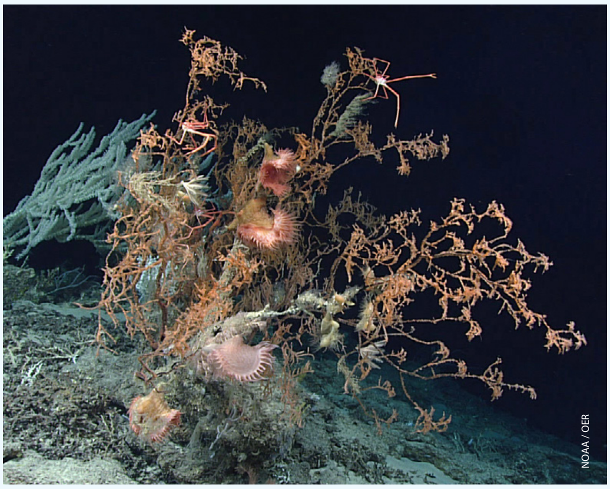
Ocean circulation

How does circulation regulate natural capital?

When ocean waters move, they transport heat, nutrients, oxygen and carbon dioxide, along with the marine organisms and larvae that cannot swim. For example, the Atlantic meridional overturning circulation (AMOC) plays a key role in supplying heat to the UK and Europe, and is in part responsible for western Europe's mild winters. It is the main source of oxygen required for deep water ecosystems (Box 1), but also increases the rate of ocean warming and acidification in the deep North Atlantic compared to other areas[7]. In the last 50 years, 90% of warming on Earth has occurred in the ocean. Rapid changes in AMOC during the last Ice Age are thought to have been responsible for equally rapid changes in northern hemisphere temperature and rainfall[8]. Reinvigoration of the AMOC after the Ice Age may have helped important ecosystem engineers such as cold-water corals expand northwards by facilitating northward larval transport[9]. In modern times, changes in ocean circulation have been shown to affect stocks of plankton, cetaceans and fish[10], including whiting and mackerel, and have likely contributed to disputes over fishing rights (Box 2)[11].

Box 1: Deep-sea ecosystems

The deep North Atlantic Ocean contains important deep-sea ecosystems. Cold-water corals and sponges form extensive biogenic habitats, which in turn support many other species of invertebrates and provide important shelter and spawning grounds for demersal fish[12–15]. Cold-water corals are slow growing (at rates of only millimeters to centimeters each year[16]) and therefore highly susceptible to damage by human activity such as fishing. They are also less able to move to colonise new areas than mobile organisms, relying on ocean currents to transport and deposit their larvae. They meet the criteria of Vulnerable Marine Ecosystems (VMEs)[17] and Ecologically or Biologically Significant marine Areas (EBSAs)[18], and have become a priority for marine protected areas.



Box 2: Icelandic fisheries

In recent years, waters around Iceland have seen a temperature increase of 1-2°C[19,20]. This increase was associated with a change in ocean circulation, bringing more water from the subtropics to the Iceland Basin. It is likely that this change was part of a long-term shift in circulation during the 20th century, unique in the last 10,000 years[20], not just a short-term fluctuation. The shift has meant that the Icelandic fishery for capelin has declined, but other species like mackerel and monkfish have increased. The appearance of significant numbers of mackerel in Icelandic waters has caused friction between Iceland and Norway, the UK and the EU. A similar picture has been seen in Greenland, where the mackerel fishery is expanding as a result of ocean warming[11]. Continued changes to local fisheries are likely to be a feature of climate change in the 21st century.

Monitoring schemes

Several technologies and methods are used to monitor North Atlantic circulation. Since the 1990s, satellite measurements have provided spatially extensive, high-resolution measurements for a restricted range of sea surface properties, including temperature, and sea surface height from which circulation can be inferred. In order to gain knowledge of the entire water column, *in situ* instrumental measurements of physical and chemical properties of the ocean are made using technologies including stationary arrays of instruments attached to buoys, and drifting floats and gliders that collect data as they move through the ocean. Continuous monitoring of the ocean is provided by instrumental arrays at strategic locations throughout the North Atlantic[21,22], as well as brief or sustained studies of particular areas by dedicated oceanographic research expeditions[23]. Key strategic monitoring arrays of the AMOC include the RAPID array that extends across the North Atlantic at 26°N, and the OSNAP array that spans the North Atlantic at subpolar latitudes (~53-60°N; Fig. 1). These arrays require continual funding to maintain them, but provide the gold standard of ocean observations.

There is sparse spatial and temporal coverage of *in situ* data prior to the recent period of investment in dedicated ocean monitoring programmes by the UK and international community, which hinders our understanding of ocean circulation before this time.

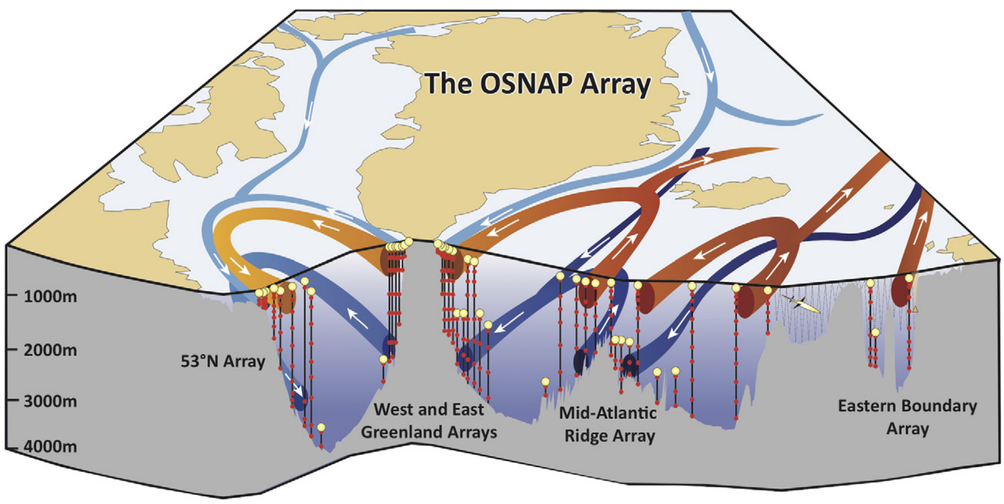


Figure 1: A schematic of the Overturning in the Subpolar North Atlantic Program (OSNAP) array. Warm currents in the upper one kilometre that flow north from the Gulf Stream and North Atlantic Current are shown in red. The warm water is made colder as it flows round the subpolar gyre and in the Nordic and Labrador Seas east and west of Greenland. The cold waters in blue return southward to the global ocean at depths of one to four kilometres. To continuously monitor the strength and structure of all these currents, arrays of moorings are deployed between Newfoundland and West Greenland, and East Greenland and Scotland. Every two years, over a period of three summer months, all the moorings are recovered during research expeditions. In the Eastern Boundary Array, autonomous gliders (yellow vehicle with black fins) patrol regions where it is difficult to install moorings safely (mainly due to fishing). Gliders have an endurance of six to eight months, and are deployed and piloted by the Scottish Association for Marine Science.

Knowledge about the ocean prior to the last few decades is gained by the collection and analysis of material from the geological record, which includes marine sediment cores and corals. Changes in ocean circulation are inferred from these geological archives using indirect measurement of key ocean properties, called 'proxies', which are typically calibrated using modern ocean datasets or laboratory experiments. There are only select locations where the geological archives can offer sufficient temporal resolution to examine changes on timescales relevant to modern climate change.

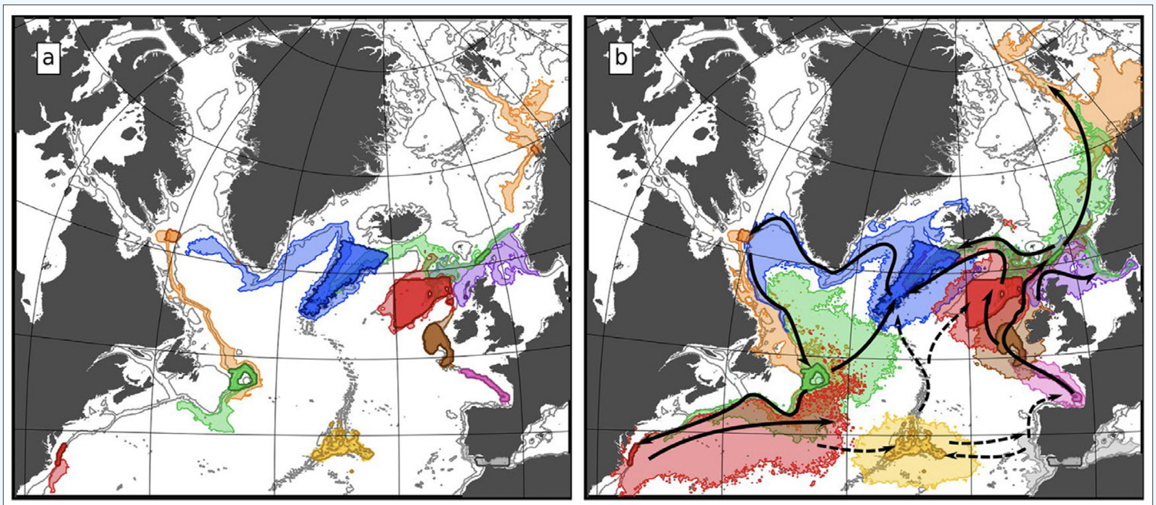
Changes in circulation

Decadal variability

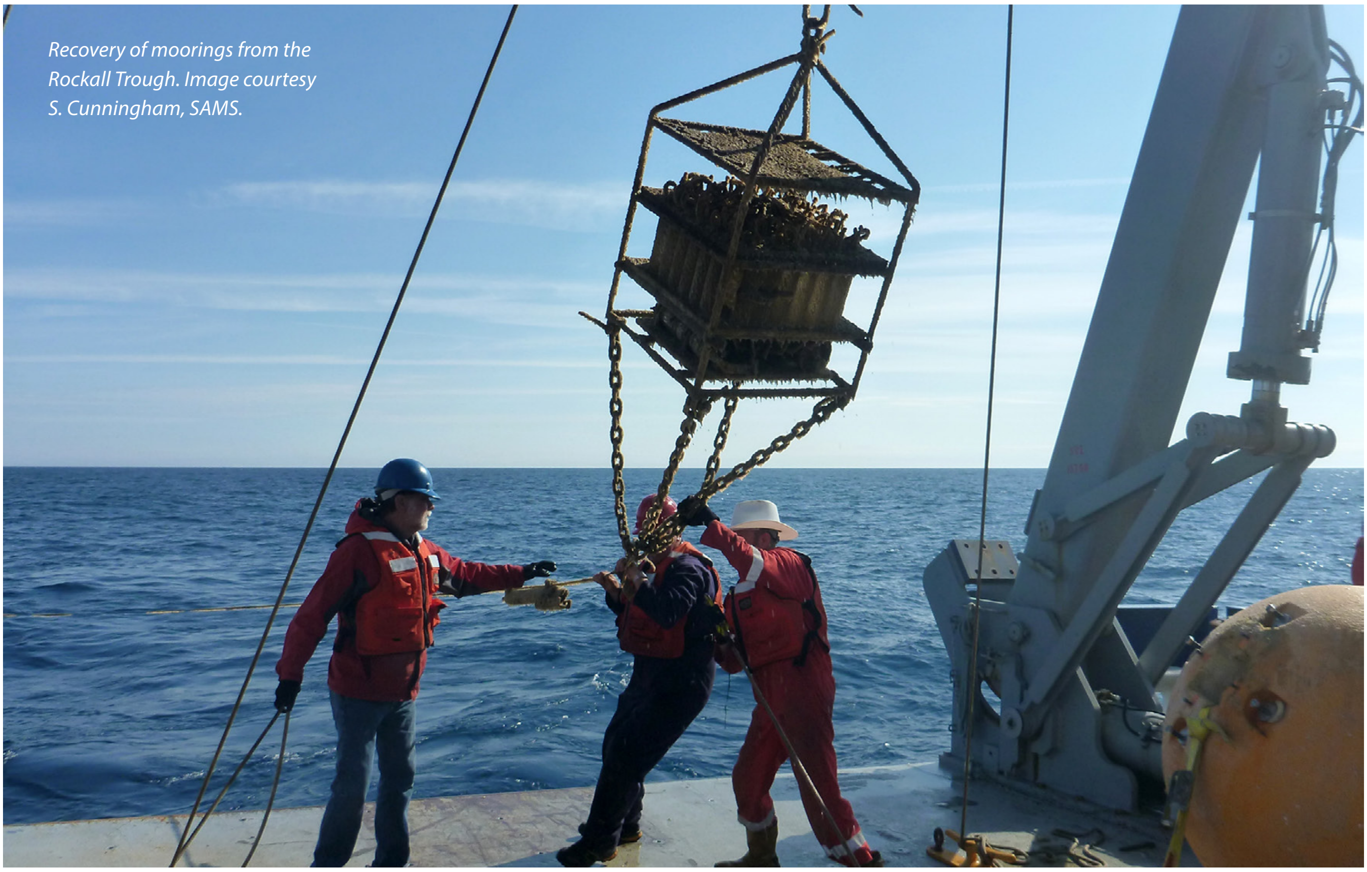
Reliable estimates of variability in the AMOC have only become available since the establishment of the 26°N RAPID array in 2004. This has revealed a decline in the AMOC of ~15% from 2004 to 2018[22,24]. Longer timescale datasets are available for the surface North Atlantic circulation. These show that there has been large decadal variability in the position of the boundary between cold, fresh subpolar water and warm, salty subtropical water. This boundary runs through the north-east subpolar Atlantic and causes large changes in the proportion of subpolar versus subtropical water masses present in the Iceland and Rockall basins[20,25]. This surface ocean variability has likely been driven by natural variability in atmospheric circulation. As outlined above, it has also been linked with ecosystem change in the north-east Atlantic, including larval transport by currents (Box 3).

Box 3: Ecosystem connectivity

The degree to which non-motile ecosystems are connected to one another in the ocean is controlled by ocean currents. Greater connectivity tends to mean greater resilience to change and more rapid recovery[27]. The flow of larvae between marine protected areas can be studied using high-resolution ocean models[28]. These studies suggest that the pathways followed by larvae are not very dependent on the overall strength of the AMOC, although examination of only the large-scale strength of the AMOC, rather than more detailed changes in circulation patterns, may not be sufficient to capture the most relevant variability. However, the larval pathways are strongly dependent on changes in atmospheric circulation and its impact on surface ocean circulation. For example, there was more connectivity between MPAs in the North-East Atlantic when there was a large difference in sea level pressure between Iceland and the Azores. Persistent changes in atmospheric circulation due to ongoing climate change are therefore likely to alter marine connectivity, impacting the long-term effectiveness of static MPAs. However, our ability to produce realistic simulations of connectivity is restricted by our poor understanding of the larval biology of deep-sea organisms. ATLAS findings have clearly shown how important the biology and behaviour of larvae is in determining connectivity[29].



Figures illustrating the importance of larval behaviour in determining theoretical deep-sea ecosystem connectivity between ATLAS case study areas. Panel (a) shows the dispersal of simulated larvae that don't spread far from the seabed compared with (b) the most dispersive simulation by larvae capable of reaching fast-flowing surface currents. Reproduced from Gary et al. (2020)[29].



Recovery of moorings from the Rockall Trough. Image courtesy S. Cunningham, SAMS.

20th century changes

Proxy measurements on marine archives have revealed significant long-term changes in the properties and circulation of the subpolar North Atlantic. Key deep-sea currents that form part of the AMOC weakened around 200 years ago, during the end of a cold period called the Little Ice Age, and have stayed weak since[26]. This weakening was likely caused by increased freshwater input to the subpolar North Atlantic caused by melting glaciers and sea ice, which can partly be attributed to anthropogenic warming.

Multiple lines of evidence show that there has been an exceptional change in the subpolar North Atlantic during the 20th century. Subpolar marine productivity has decreased and more subtropical water is reaching the Iceland Basin and Svalbard in the eastern and northern subpolar gyre regions respectively[20,30]. At the same time the central subpolar gyre region has not warmed[31], and parts of the western Atlantic have warmed[32]. These changes are explained by a shift in ocean fronts and surface ocean currents that can be caused by changing atmospheric circulation and the input of freshwater from the Arctic and the Greenland ice sheet. Work by ATLAS shows that some of these changes are unprecedented when compared to the last 10,000 years[20]. These changes are also implicated in the recent appearance of mackerel fisheries around Iceland and Greenland (Box 2).

Future perspective

Climate models have consistently projected that the AMOC would get weaker by around 34-45% during the 21st century[33]. These models find it unlikely that the AMOC will rapidly switch to a different state. However, only a small selection of these models find a trend over the 20th century, and therefore most do not agree with the proxy and reconstruction data in this respect[31]. Models are more variable in their projections of the detailed surface circulation of the North Atlantic, and they are known to underestimate variability in the North Atlantic. We expect that decadal variability will continue, but it is not well known if the magnitude of variability will change. The best strategy for analysing ongoing changes is therefore to sustain the monitoring efforts that have been developed and to support work to unravel the basic biology and ecology of keystone deep-sea species. While these approaches are at the heart of the iAtlantic project plan (2019-23) these efforts must be sustained in the long term using the full institutional diversity of university and marine research centre networks.

Other changes in ocean state

The changes in ocean circulation outlined above coincide with a number of other changes in ocean state. These include general ocean warming, which is contributing to a net northward movement of some marine species by around 25 km per year[34], ocean acidification, and deoxygenation. Ocean acidification is likely to have a greater effect at higher latitudes, such as in the North Atlantic, and at greater depths closer to the calcium carbonate saturation horizon where cold-water corals have proliferated in the North Atlantic[35]. The North Atlantic is also the the region where acidification is transported into the deep ocean most rapidly[7]. The multiple stressors impacting the North Atlantic will likely lead to very significant ecosystem changes by 2100. For example, ATLAS research research points to a marked decrease (by 28-100 %) in suitable habitat for cold-water corals, and a northward movement of commercial fish stocks by 2-10° latitude[36]. This work will be further developed through iAtlantic project.

Future impacts on marine resources

Surface ocean

The upper and surface oceans are the source of many fisheries catches. In general terms, it is very likely that warming oceans will drive many species further northward, including commercial fish stocks (see above). Changing ocean circulation will act to modify the extent to which this process occurs in different regions. In some cases, warming will occur rapidly, potentially leading to fisheries disputes (Box 2). Changing circulation will also modify the productivity of our seas and the connectivity between different ocean areas, and will therefore impact the effectiveness of marine protected areas. However, without further direct observation and refinement of our understanding of why certain circulation shifts occur, it is unlikely that we will be able to accurately project these localised effects using current climate modelling.

Deep ocean

As outlined in Box 1, the deep ocean contains many important ecosystem engineers, including cold-water coral reefs and sponge grounds. Changing ocean circulation will likely alter the location and strength of deep-sea currents, upon which such ecosystems depend for food. These vulnerable deep-sea ecosystems will also feel the effects of surface ocean changes in productivity, deep ocean acidification, and oxygen concentration, resulting in a loss of suitable habitat area[36].

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Left: Deployment of moorings on the OSNAP line in 2019. Image courtesy P. Holliday, NOC.

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