Project news

Issue 5 | June 2022

iAtlantic

INTEGRATED ASSESSMENT OF ATLANTIC MARINE ECOSYSTEMS IN SPACE AND TIME

Thriving cold-water corals off Ireland. Image courtesy MARUM/Univ. Bremen

Life in a changing ocean

In this issue...

Message from Murray

We're halfway through 2022 – truly a super year for the oceans marked at this midpoint by the UN Ocean Conference in Lisbon. Back in March we saw the fourth round of negotiations for a new legally-binding treaty to manage biodiversity beyond national jurisdiction move online, with the fifth BBNJ negotiation session scheduled in-person at the UN in New York in August.

But while meetings and negotiations take place across our planet, the concentration of carbon dioxide in our atmosphere continues its remorseless climb and it's the global ocean, and the ecosystems it supports, that are at the frontline. We can never forget that the ocean has already absorbed over 90% of global heating and around 25% of human CO_2 emissions.

In this newsletter we focus on iAtlantic's work to assess deep and open ecosystem status across the Atlantic Ocean and relate this to climate change and other human uses, notably past fishing or hunting activities.

To tackle this huge challenge, iAtlantic has been assembling a diverse collection of ecosystem time series from plankton to whales to cold-water corals and hydrothermal vents. Over the last two years we've been scrutinising these time series to see if there is evidence that ecosystems across the Atlantic are showing signs of stress and strain, even being likely to tip across into altered states. Lea-Anne Henry, Marjolaine Matabos and the 'Drivers of ecosystem change' team describe some of the exciting results they're now finding (p4-12). As our ocean warms fish species are on the move, with whole regions experiencing 'tropicalisation' as warmer tropical species extend their ranges to cooler regions (p13-15). In other places we're finding more stability – for instance the animals at the Lucky Strike vent field show very little change over time, illustrating how vulnerable they would be if disrupted by deep-sea mining.

But iAtlantic isn't only relying on what we can glean from present-day ecosystems. We're pushing the boundaries using information from the past too. Dierk Hebbeln and Rodrigo da Costa Portilho-Ramos have painstakingly analysed what's driving the boom-and-bust of Atlantic cold-water corals in the geological record and finding just how important food supply has been to sustain vibrant deep-sea coral reefs (p16-17). This forensic approach to understanding marine life in the past is an essential part of understanding present-day ocean change. Imagine if we can begin to analyse the genetics locked in fragments of ancient DNA from plankton preserved in ocean sediments: we might just open the floodgates on understanding how past plankton populations worked – perhaps including how much food they could have produced. Check out how Caitlin Selway and colleagues have been able to extract ancient DNA from samples up to 20,000 years old (p30-31).

A newsletter like this can only give a snapshot of that iAtlantic is doing. Despite the headwinds of the last two years, we're still on course and have produced 53 papers with 16 currently in revision – do follow our Twitter (@iAtlanticEU) and other feeds for regular updates. Huge thanks to everyone in the project for your dedication and amazing work. Look forward to seeing you at our in-person General Assembly in October in beautiful Florianópolis, Brazil!

J Murray Roberts
iAtlantic Coordinator
Edinburgh, 23 June 2022

iAtlantic General Assembly 2022

Having not been able to meet in person since the iAtlantic kickoff meeting in June 2019, we are very excited to be planning the 2022 iAtlantic General Assembly as an in-person meeting in Florianópolis, Brazil on 10-14 October 2022. We highly encourage all parters to attend in person, though there will be hybrid options too.

In addition, we have a couple of capacity building events taking place either side of the General Assembly: a workshop on ocean governance is planned for Sunday 9 October, and the long-planned cold-water coral taxonomy workshop will take place at the Universidade Federal de Santa Caterina (UFSC) in Florianópolis the weekend after the GA, 15-16 October 2022.

More details will be available on the iAtlantic website in due course.

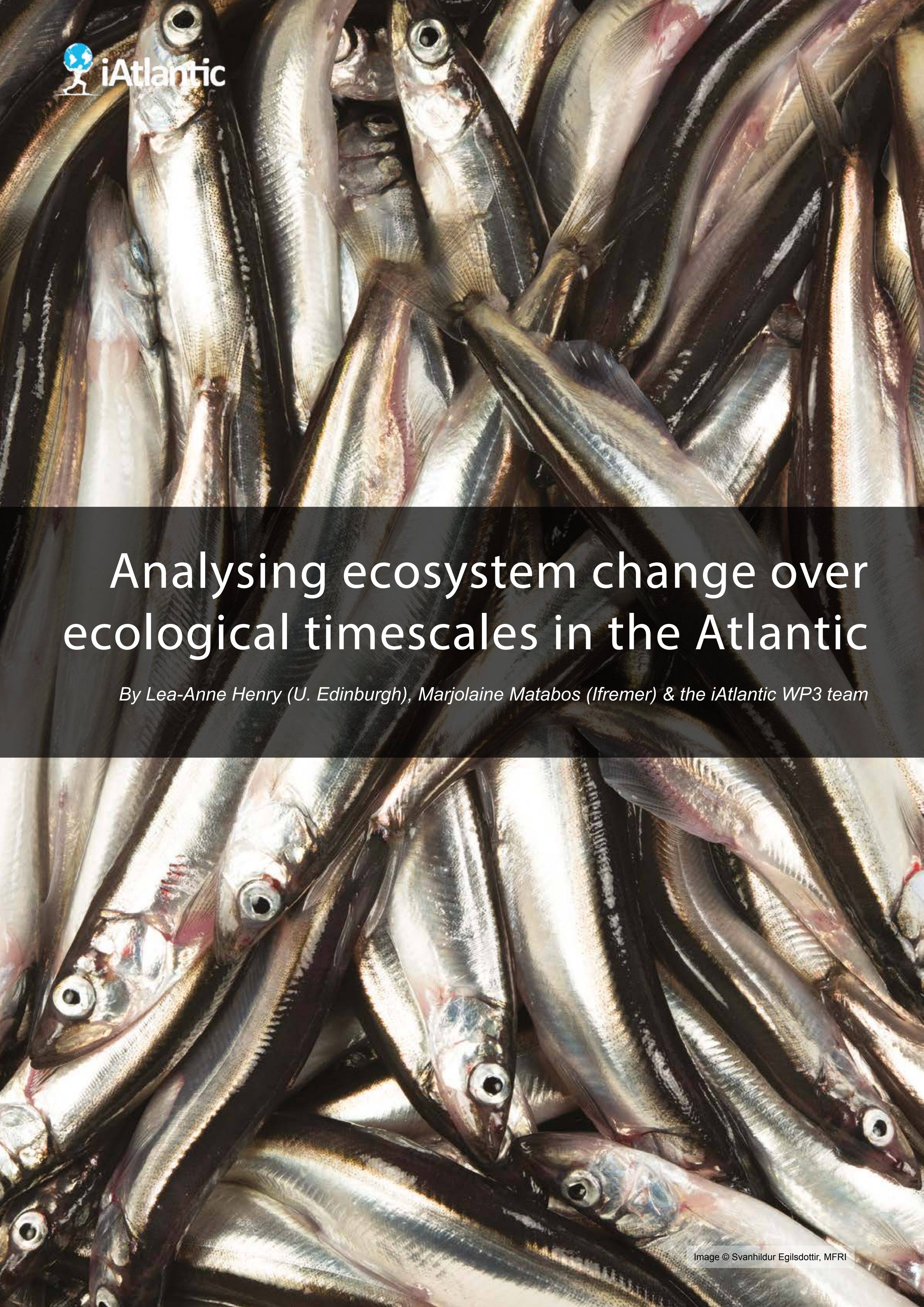
iAtlantic at UNOC2022

This edition of the iAtlantic newsletter is timed to coincide with the gathering of ocean experts, conservationists, scientists and policymakers at the UN Ocean Conference (UNOC2022) in Lisbon at the end of June.

The conference brings together the global ocean community to support the implementation of Sustainable Development Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development. Postponed from 2020 due to Covid-19, the event is co-hosted by the Governments of Kenya and Portugal under the overarching theme of "Scaling up ocean action based on science and innovation for the implementation of Goal 14: stocktaking, partnerships and solutions". It seeks to accelerate much needed science-based innovative solutions to start a new chapter of global ocean action, and we anticipate that iAtlantic has much to offer to the conversations and discussion through the week.On Wednesday 29 June, an iAtlantic side event "*Scaling up ambition in science partnerships to address challenges at ocean basin scale: examples from the iAtlantic project*" will focus on the importance of international, cross-sectoral collaboration to provide the science needed to address the most pressing ocean challenges. We are delighted and privileged to welcome opening remarks from Dr John Bell (Director 'Healthy Planet', Directorate-General for Research & Innovation, European Commission), Mr Lawrence Hanson (Associate Deputy Minister of Fisheries and Oceans, Canada), and Dr Jane Lubchenco (Deputy Director for Climate & Environment, U.S. White House Office of Science and Technology Policy). The main speaker programme features presentations from our partners across the Atlantic, representing academia, government (DFO, NOAA), industry (IOGP), and civil society (IUCN). A special highlight of this event is a live link to scientists on the NOAA Okeanos Explorer research vessel in the high seas of the mid-Atlantic, where they will be investigating previously unexplored areas of the Charlie-Gibbs Fracture Zone. Collectively, our speakers will demonstrate how shared scientific ambition can be an effective driver for innovative and productive partnerships that bring benefits to the wider global ocean community. Full details are on the iAtlantic UNOC2022 side event webpage.

In the margins of the conference, iAtlantic will also convene its first Stakeholder Dialogue event. These events allow us to formally engage with a range of global, regional and sectoral stakeholders to ensure feedback into relevant areas of iAtlantic research, explore how iAtlantic results will be used by different end-users, and where sectoral groups may be able to contribute knowledge, data and expertise to the project effort. Results from iAtlantic will be presented, ideas exchanged, and relevant issues discussed. This first Dialogue event is tailored towards the NGO and civil society community - of which many organisations will be present in Lisbon for the UNOC. Full event details are online at the event webpage.

So, we look forward to a very busy and productive week in Lisbon, and would like to extend our thanks in advance to all our presenters and those that support our iAtlantic events.



Analysing ecosystem change over ecological timescales in the Atlantic

By Lea-Anne Henry (U. Edinburgh), Marjolaine Matabos (Ifremer) & the iAtlantic WP3 team

Image © Svanhildur Egilsdottir, MFRI

Within iAtlantic, a major component of our work focuses on understanding the drivers of ecosystem change at regional to ocean scales across different ecosystems. This research takes a multidisciplinary approach to investigating ecosystem stability, vulnerability, and tipping points over inter-annual to millennial timescales. With a focus on ecosystem change over the last 50 years, the iAtlantic WP3 team led by Lea-Anne Henry and Marjolaine Matabos recently completed a major analysis that reports on change over ecological timescales, and identified several cross-cutting issues for iAtlantic to consider going forward.

With increasing exploitation and industrialisation of the oceans and accelerating climate change, marine ecosystems have experienced a lot this last century. Decision-makers and wider society now recognise the urgent need for comprehensive assessments of the status, trends and tipping points of marine ecosystems. Area-based management tools for planning a sustainable blue economy include marine spatial planning, strategic environmental assessment or environmental impact assessment. These tools require us to understand the drivers of ecosystem change and to predict impacts of our plans, policies, programmes, strategies and projects under future climate change scenarios. But for deep-sea and open-ocean biomes, there is a high degree of uncertainty about how naturally variable these ecosystems are or what drives these changes. It's therefore difficult to speculate how human activities will impact ecosystems in these places; it's then even harder to predict how cumulative impacts of climate change and human activities could alter ecosystems and the services they provide.

Figure 1: The iAtlantic study areas.
For key and details see www.iatlantic.eu/our-work/study-regions

The iAtlantic project developed an entire workstream on "Understanding drivers of ecosystem change" to deliver an international and multidisciplinary effort that would improve our understanding of ecosystem stability, vulnerability and tipping points in each of the twelve iAtlantic study regions (Figure 1). But the lack of robust, long-term observations of marine species and ecosystems over the last 50 years in the deep sea and open ocean still remains a massive challenge, even in the well-studied Atlantic.

International collaborations and networking opportunities called for by the Belém and Galway Statements extended our capacity to create new time series in these realms and develop the approaches we use to understand drivers behind these changes. Most of our analyses were undertaken by early career researchers (ECRs) like Edson Cavalcante dos Santos (Figure 2) for whom such networks are critical, but it is also our ECRs that have helped to showcase new methods for analysing such complex datasets, which have revealed new trends – even in well-studied datasets.

We analysed various ecosystem compartments, from bacteria and primary producers, zooplankton to groundfish and benthic invertebrates, to whales, swordfish and sharks – many of which are of great conservation interest and value to the Atlantic socioeconomy (Figure 3).

Methods to collect and reconstruct our time series were themselves as diverse as the study regions, species and ecosystems we studied. We are extremely grateful to the many collaborators, institutes, governments and authorities for permission to make use of the facilities, the data and the many experts who advised analysts along the way. Marine observatories were instrumental to our work, including those from the European Multidisciplinary Seafloor and water column Observatory (EMSO), the Cape Verde Ocean Observatory (CVOO) and the Bermuda Atlantic Time-Series (BATS). Long-term monitoring programmes and surveys of zooplankton, cetaceans, and groundfish off study regions like Nova Scotia in eastern Canada, and the North Atlantic Sightings Surveys (NASS) off Iceland were key, as was local ecological knowledge of humpback whales in the Sargasso Sea. We relied heavily on fisheries-dependent data in our South Atlantic study regions. These were sourced from the International Commission for the Conservation of Atlantic Tunas (ICCAT) and from the University of Vale do Itajaí's (UNIVALI) monitoring of landed catches of groundfish along the Brazilian Meridional Margin. The latter dataset comes from

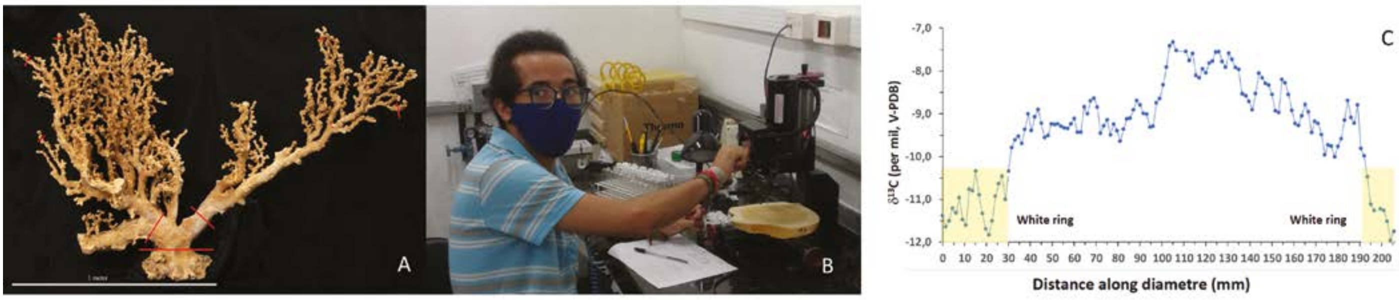


Figure 2: A) Scientists sent deep-sea coral samples from Canada to Brazil and the EU for geochemical analysis to study carbon sources (scale bar 1m – photo courtesy of DFO & Ellen Kenchington), including work done by B) undergraduate student Edson Cavalcante dos Santos to reconstruct coral age (photo courtesy Christian Millo). C) This international collaboration revealed the gorgonian Paragorgia arborea *underwent wide swings in food sources over its lifetime in the Davis Strait, northern Canada.*

Figure 3: International collaborations unlocked a range of time series across different species and ecosystems, e.g., A) zooplankton (photo courtesy Erica Head), B) vent mussels (photo courtesy Marjolaine Matabos), C) amphipods (photo from Horton et al. 2020), D) whitemouth croaker (photo courtesy Rodrigo Sant'Ana), E) tuna (photo courtesy Roberto Bavares & Dimas Gianuca), F) blue shark (photo courtesy Roberto Bavares & Dimas Gianuca), G) humpback whale (photo courtesy Andrew Stevenson), H) microbial mats (photo courtesy Marjolaine Matabos), and I) zoanthids (photo courtesy Marjolaine Matabos).

UNIVALI being able to support governmental requests for oceanic and deep fisheries development and management, and the licensing processes of Brazilian offshore oil and gas exploration activities.

Besides classical survey and monitoring methods, alternative approaches such as structure from motion photogrammetry, capture-recapture modelling from whale fluke photos, the use of acoustic Doppler conductivity profilers (ADCPs), and palaeoceanographic and geochemical proxies of ecosystem change over centuries to millennia were all used to reconstruct time series (Figure 4). All to say, our best efforts led to improving the understanding of what's driving ecosystem changes in each place.

The Atlantic community must continue working towards standardising and aligning ocean observations. We adopted a more flexible 'place-based approach': this allowed existing time series to be integrated into ecosystem assessments for each iAtlantic study region. But we harmonised the approach by setting a common suite of overarching questions about drivers of change and by creating statistical workflows with common design principles to guide analyses.

Through this flexible place-based approach, several themes emerged about ecosystem change over the last 50 years that cross-cut our study regions and the ecosystems we studied.

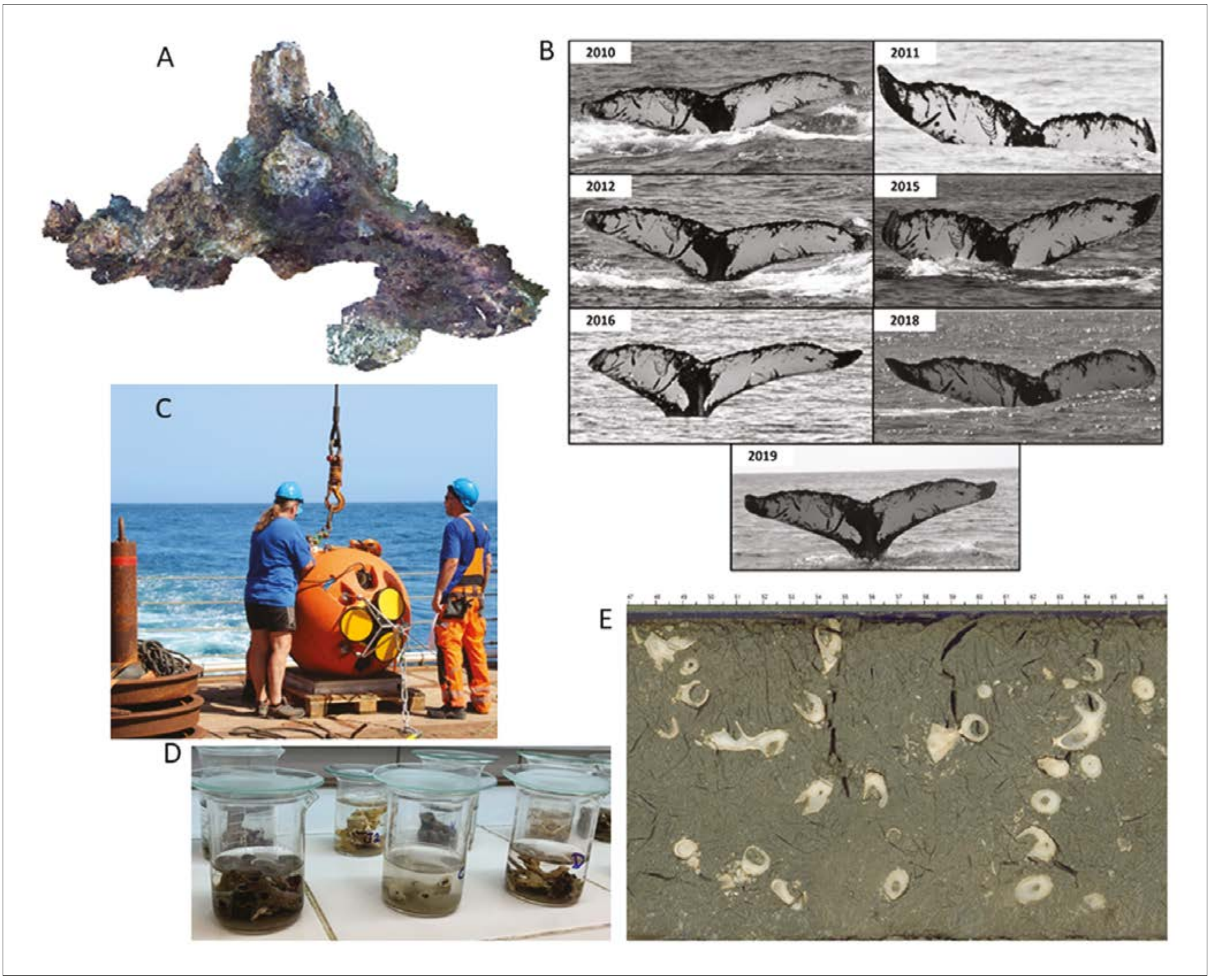


Figure 4: Reconstructing time series was made possible using structure-from-motion photogrammetry on A) hydrothermal vents (photo courtesy Marjolaine Matabos), B) capture-recapture modelling from whale fluke identification (photos courtesy Andrew Stevenson), C) trialling the use of ADCPs to reconstruct inter-annual changes in mesoplankton (photo courtesy Helena Hauss), D, E) reconstructing ecosystem changes from cold-water corals over decades and millennia (photos courtesy Christian Millo and Dierk Hebbeln, respectively).

Cross-cutting theme #1: Abrupt ecosystem changes in the late 1990s to early 2000s

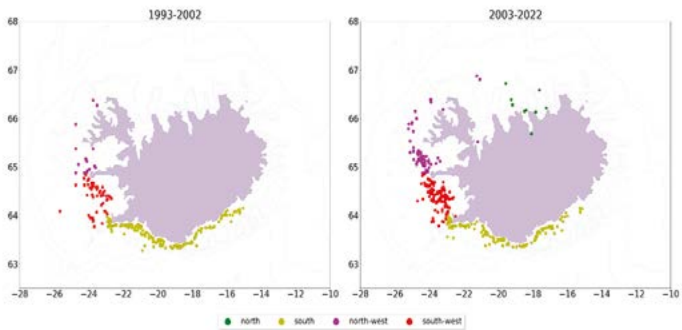
First, we discovered statistical 'breakpoints' in our datasets, which suggest tipping points in conditions were reached in many study regions, especially around the late 1990s and early 2000s. Breakpoints are strong, significant and abrupt changes in species or ecosystems. The late 1990s and early 2000s coincided with larger-scale surface, mid- and deep-water oceanographic trends reported from the surface of the open ocean to the abyss across the Atlantic.

Some of these breakpoints involved commercially important fish stocks. This was particularly evident off Iceland. For example, in 2003 researchers from the Marine and Freshwater Research Institute (MFRI) found catches of capelin at maturity stage 6 and higher had significantly expanded their range north and westward around Iceland, indicating a large and abrupt redistribution of fish stock spawning habitat (Figure 5).

MFRI scientists also discovered capelin larval connectivity was highly sensitive to spawning habitat location: when larval particles were virtually released in a simulated model environment, the more northerly Latragrunn and Snæfellsnes release sites gradually increased connectivity to Greenland, while release sites just due west at Faxaflói hardly connected at all (Figure 6). Therefore, recent increases in juvenile capelin in Greenlandic waters may in part be explained by enhanced larval connectivity and recruitment from northwestern spawning grounds off Iceland since 2003.

Meanwhile, the late 1990s to 2000s also coincided with a significant breakpoint in the groundfish surveyed from the cooler, fresher waters to the northwest of Iceland. Here, MFRI scientists discovered Norway haddock, capelin, saithe, and haddock rapidly becoming caught in more of their survey stations after 1999, whereas the number of stations with records of other species like halibut, plaice, redfish and polar cod rapidly decreased. Besides these shifts in composition, the total beta diversity in both the northwest and southwest of Iceland both abruptly increased after 1999 (Figure 7).

Monkfish (Figure 8) are a species for which Iceland is located at the northernmost border of their habitable range. However, a weaker subpolar gyre bringing warmer and more saline water masses reached Iceland by 2000. In response, the monkfish centre of gravity moved westward, followed by a change towards the north along with increased biomass and effective area occupied. Just before or around 2010 this trend reversed again and while sea temperature remained high until 2015 (Figure 9), salinity dropped markedly around the same time as the declines in monkfish.



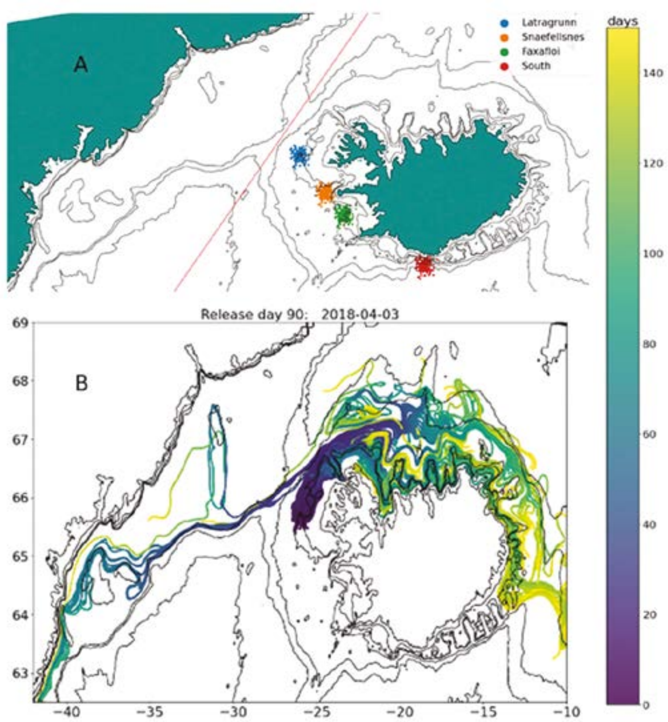


Figure 5 (above): All catch locations of capelin at maturity stage 6 and higher between 1993 and 2002 (left) and 2003 to 2019 (right). Catch locations north of 64.85° N are coloured red, those south of it in blue.

Figure 6 (right): A) Locations of four modelled particle release sites for simulated larval drift experiments. The red line separates areas for which the simulated larvae go to nursery areas in Greenland from those that remain in Icelandic waters. B) Spatial distribution patterns of larval drift trajectories released from Latragrunn over a 140-day period, with colours reflecting the age of the particles (simulated larvae) since spawning (day zero, purple) until day 140 (yellow). Shown are particles that were released at five-day intervals in 2018 between 9 March (day 65) and 3 April (day 90), assuming diurnal vertical migration.

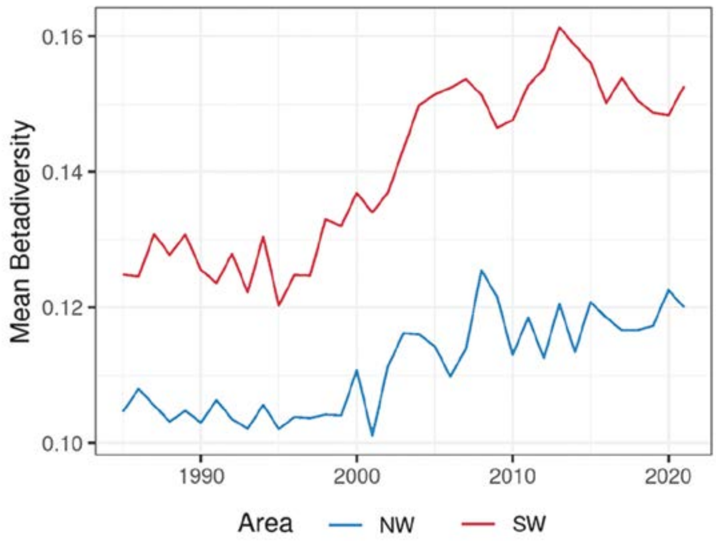


*Figure 7 (left): Annual mean beta diversity per study region based on the spring Icelandic Groundfish Survey for 1985-2021 (NE area: blue line and SW: red line). Figure 8 (right): A juvenile monkfish (*Lophius piscatorius*) approx.12 cm in length (photo courtesy of Magnús Thorlacius).*

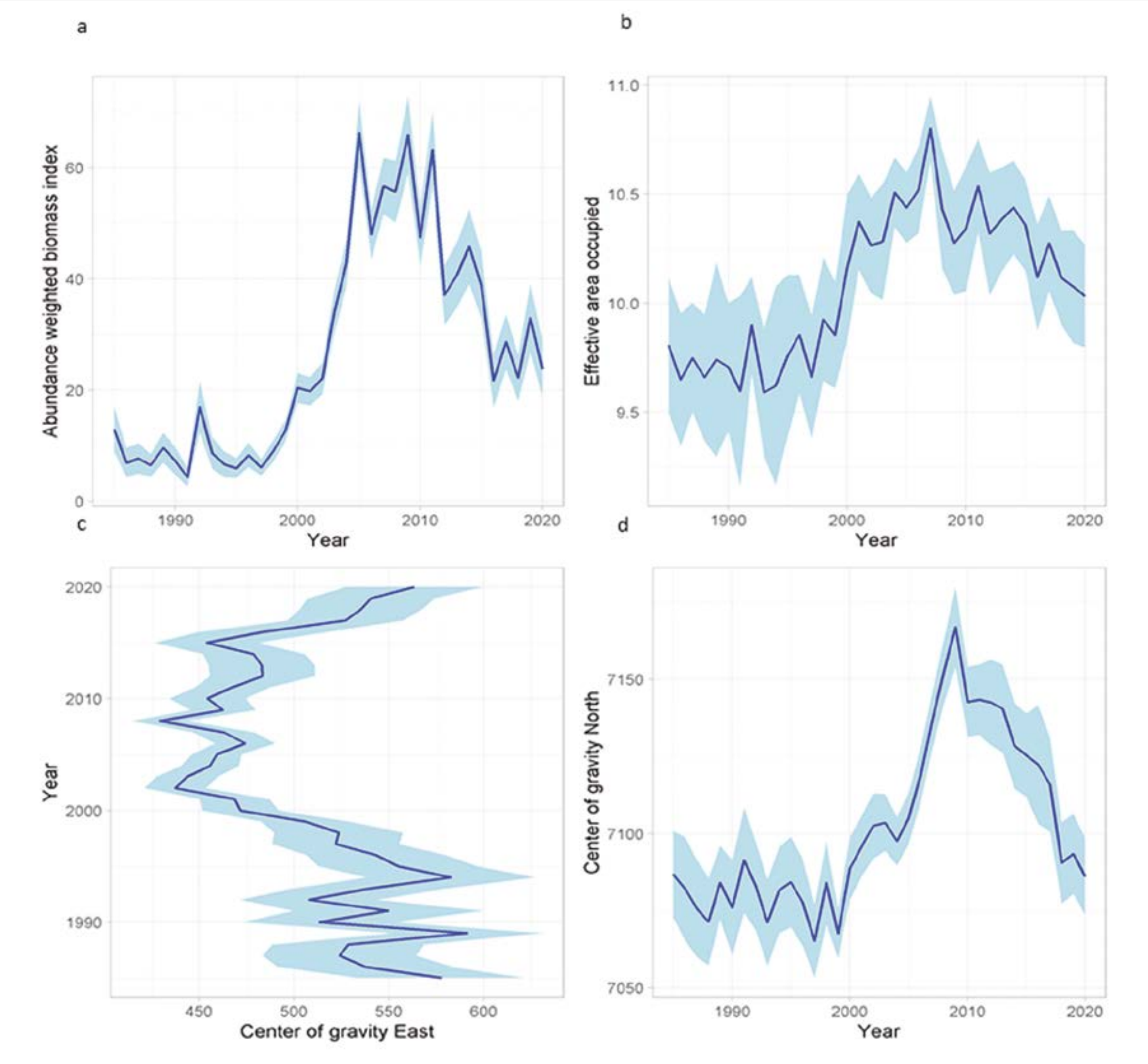


Figure 9: (a) Monkfish biomass index, (b) effective area occupied and (c) centre of gravity east and (d) north, estimated using the VAST package.

Cross-cutting theme #2: Tropicalisation of fauna and relationships with sea temperature

From eastern Canada to the Malvinas Current, and from Iceland to South Africa and the Walvis Ridge, species with warm-water affinities have become more abundant and many now dominate communities. While sea temperature alone may not be 100% responsible for driving these trends, iAtlantic discovered that long-term ocean warming has heralded in a new era of widespread species “tropicalisation”.

In eastern Canada on Nova Scotia’s continental slope, scientists at Bedford Institute of Oceanography, University of Edinburgh and Instituto Español de Oceanografía discovered that zooplankton species with warm-water affinities now characterise the community in both the spring and autumn, with cooler water taxa disappearing over time. Meanwhile on the Brazilian Meridional Margin, the Brazil-Malvinas Confluence has shifted south over the past decades due to a poleward displacement of South Atlantic wind patterns, which has produced a pronounced warming region over the wider southwest Atlantic Ocean.

Here is where scientists at UNIVALI discovered declines in catches of commercially important cooler-water species of groundfish like Argentine croaker and Brazilian codling, and a notable increase in warm water species like whitemouth croaker, stripped weakfish, and grey triggerfish after 2013 (Figure 10).

Likewise, the UNIVALI team also discovered massive swings in the catches of cooler-water migratory species recorded by the International Commission for the Conservation of Atlantic Tunas (ICCAT). Large migratory pelagics important to the commercial and sport-fishing sectors, like albacore and Atlantic bluefin tuna, have also significantly declined across parts of the South Atlantic, while over time yellowfin tuna and then bigeye tuna became more dominant in catches (Figure 11). With sport-fishing being so closely linked to another blue economy – marine tourism – the discovery of basin-scale thermally driven changes in such species is something multiple sectors should watch.

Figure 10: Commercially important fisheries stocks have seen a “tropicalisation” trend, with increased catches of warmer-water species now prevailing catches across Brazil and the wider South Atlantic. A) Argentine croaker, a cool-water species off Brazil; B) spotted pink shrimp off Brazil; C) monkfish off Brazil, a cool-water species; D) yellowfin tuna, a warm-water species. Images courtesy Roberto Bavares, Dimas Gianuca, Rodrigo Sant’Ana and Angel Perez.

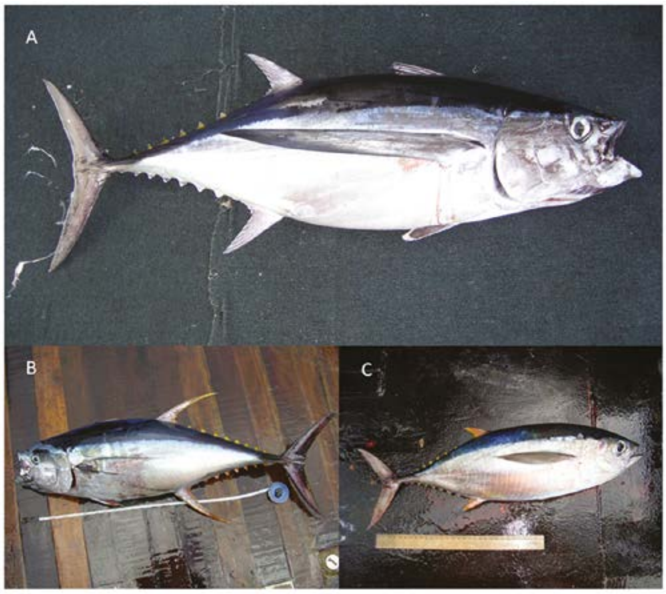


Figure 11: A tropicalisation of species targeted by both the South Atlantic commercial and sport-fishing industry has occurred: in the open ocean, catches of albacore (A) have been increasingly replaced by yellowfin tuna (B) and finally by big eye tuna (C). Images courtesy Roberto Bavares and Dimas Gianuca.

Cross-cutting theme #3: Human activities and marine management are intertwined with trends

The tropicalisation trends we discovered are all strongly related to thermal regimes, but effects of fisheries pressure itself could not be entirely discounted. Nor could the effect of the International Whaling Commission (IWC) ban on commercial whaling in 1986, and marine protected area designations. Reanalysis of beaked whale sightings in the Gully MPA recorded by Dalhousie University off eastern Canada show increases over time, which Whitehead (2020) suggests could in part relate to decreases in noise after the MPA was designated in 2004. For pilot whale, striped dolphin and white-sided dolphin, a combination of shifts in overall population size, habitat suitability and anthropogenic activity levels are also likely drivers of change (Whitehead, 2020).

In the Sargasso Sea, scientists at the University of Edinburgh and Whales Bermuda reconstructed humpback whale abundance and discovered whales have been steadily increasing since 2012 (Figure 12). Although some of these changes might relate to progressive increases in primary production recorded by the Bermuda Institute of Ocean Sciences at the Bermuda Atlantic Time-Series Study (BATS), these increases are very much intertwined with larger scale population recovery post-whaling.

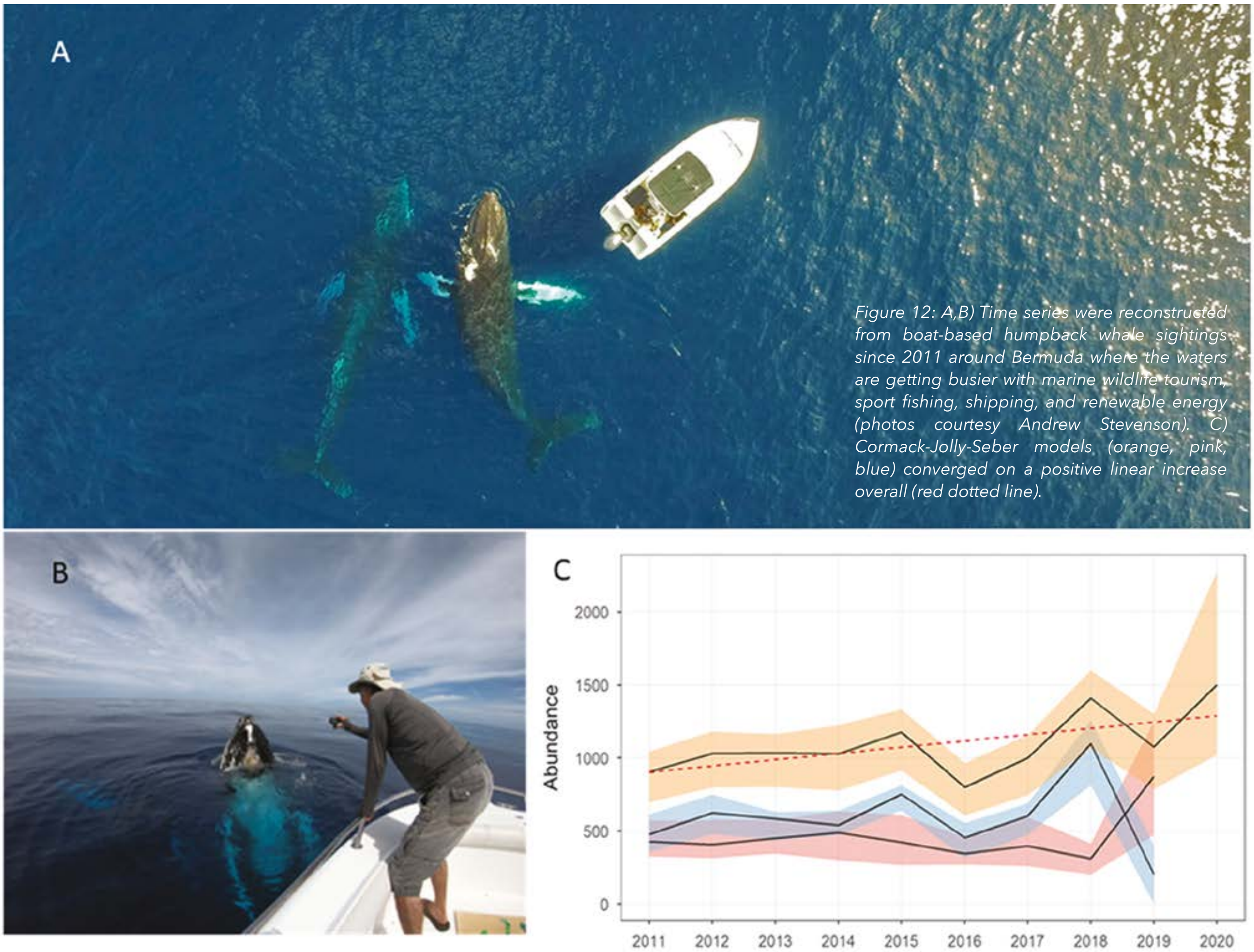


Figure 12: A,B) Time series were reconstructed from boat-based humpback whale sightings since 2011 around Bermuda where the waters are getting busier with marine wildlife tourism, sport fishing, shipping, and renewable energy (photos courtesy Andrew Stevenson). C) Cormack-Jolly-Seber models (orange, pink, blue) converged on a positive linear increase overall (red dotted line).

While all of our time series analyses come with heavy caveats, our place-based approach gives managers and spatial planning authorities a better understanding of ecosystem variability and vulnerability to climate change. It provides insights into alternative states or trajectories of ecosystems in each study region, and possible drivers that could push or tip ecosystems into a new state. Notably, scientists at Ifremer discovered remarkable long-term multi-decadal stability of benthic ecosystems at the Lucky Strike hydrothermal vent on the Mid-Atlantic Ridge. Both the vent fauna and microbes varied only slightly over time, and there was little environmental variability (Figure 13).

This is strong evidence that these climax communities are highly preserved and not used to experiencing disturbances or much environmental variability. The exploitation of hydrothermal vents like Lucky Strike would have long-lasting impacts in an ecosystem characterised by such stability,

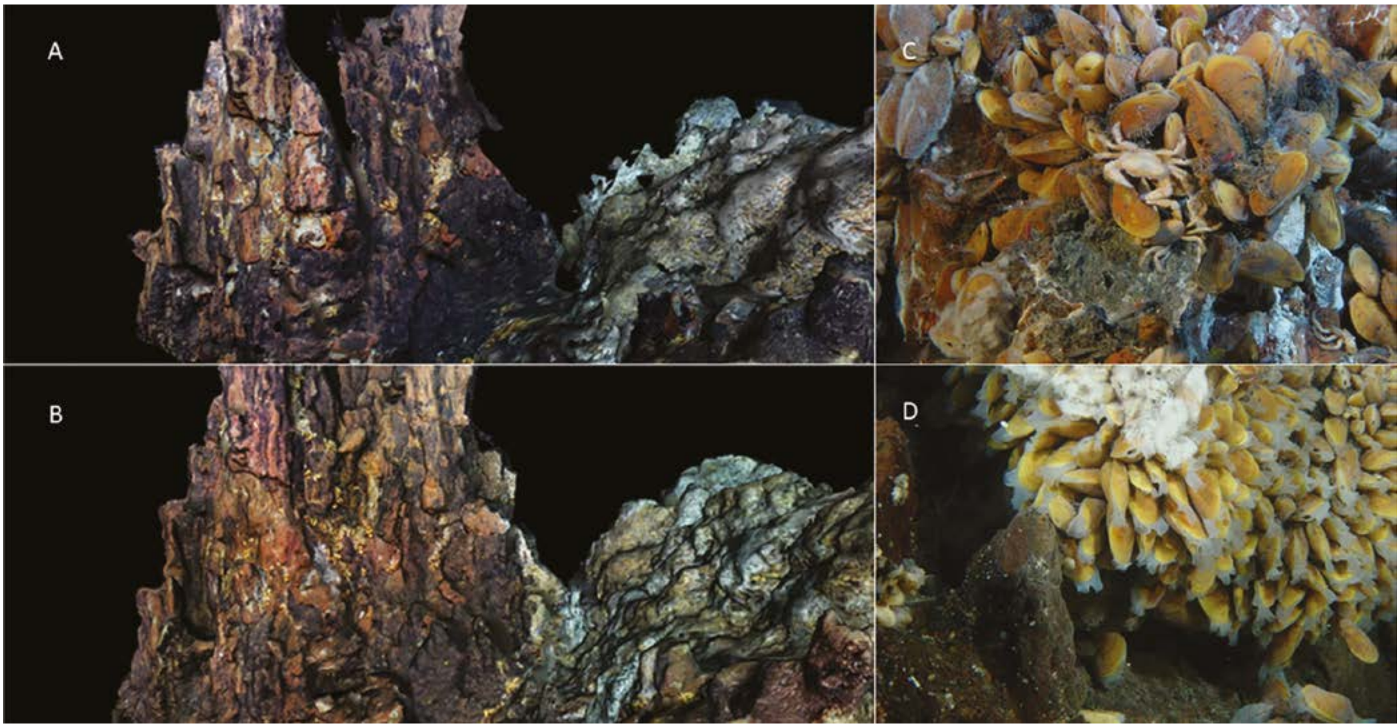


*Figure 13: A,B) Remarkable stability in the vent ecosystem at the Eiffel Tower edifice in the Lucky Strike field was recorded over time, from 2015 (image A) to 2020 (image B). C) Mussel cover (*Bathymodiolus azoricus *with a crab visitor was also stable, as was (D) white bacterial mat cover over the mussels. All photos courtesy Marjolaine Matabos.*

despite the incredibly extreme conditions of such systems, and would likely tip this ecosystem over into a significantly and likely undesirable altered state.

Next steps

Our next step in iAtlantic will take these results from the 12 study regions to drive a risk analysis, scoring the threat posed by future changes in sea temperature (T), salinity (S) and the strength of the Atlantic Meridional Overturning Circulation (AMOC). The risk analysis multiplies the likelihood of oceanographic changes in T, S and AMOC by 2070 as forecast by iAtlantic's oceanography team, using the Flexible Ocean and Climate Infrastructure Version 1 (FOCI), with the severity of ecosystem change reported by the results from this study. The risk analysis will provide decision-makers with high-level guidance about where we have the most confidence that the threats posed by changes in T, S and AMOC by 2070 are going to significantly alter ecosystems; – and therefore where we should be ramping up investments in ecosystem monitoring as we plan the blue economy so as to avoid reaching tipping points in those regions.

Noisy data, incomplete data, the lack of longer-term datasets, effects of seasonality and mesoscale oceanographic dynamics, effects of intra- and interspecific biological interactions and species phenology, and impacts of fishing fleet behaviour and management challenged all our analyses and interpretations. What needs to be done to reduce our uncertainty in place-based ecosystem assessments? Expert opinions of iAtlantic scientists involved in this study overwhelmingly noted the lack of regular and annual time series covering time periods long enough to capture oceanographic regime change at local, regional and basin scales, making it difficult to pin down specific drivers of change or tipping points. We used some alternative approaches to reconstruct time series where there were none before, and some of the more recently established datasets are going to become vital in years to come, for example local ecological records of humpback whales in Bermuda (established 2011), mesoplankton time series at the Cape Verde Ocean Observatory (established 2012). With the correct resourcing of human and infrastructure capacity underpinned by political declarations for international collaborations such as the Belém Statement and Galway Declaration, we can continue building robust time series and ensuring these are aligned with ocean observations at the correct spatial and temporal scales.

For more information on this work, please contact Lea-Anne Henry, L.Henry@ed.ac.uk

References

Horton et al. 2020. Are abyssal scavenging amphipod assemblages linked to climate cycles? Progress in Oceanography 184: 102318

Whitehead. 2020. Cetacean population trend analysis in the Gully Marine Protected Area and nearby canyons 1988 – 2019. Fisheries and Oceans Canada, Marine Planning and Conservation

Historical catches reveal signs of megafauna tropicalisation in ‘hot spots’ of the South Atlantic

By Angel Perez and Rodrigo Sant’Ana (UNIVALI)

Oceans have absorbed most of the heat increase of the atmosphere since pre-industrial times, gradually warming on average by 0.61°C. This process, however, has included large spatial variability with discrete regions warming much faster than average in the rest of ocean. These warmer regions have been called marine "hot spots" and regarded as natural labs to understand the derived patterns of ecosystem change and anticipate adaptive actions to be taken by human societies. Over 20 marine hot spots have been identified around the world by sea surface temperature anomalies, two of them in the South Atlantic. Marine hot spots have been related to changes in complex patterns of ocean circulation, but much less is known about the consequences of rising temperatures in the related ecosystems.

In the context of the iAtlantic project, we have investigated an ocean warming-related ecological process known as "tropicalisation" of marine fauna and the extent to which it may have been operating in the SW and SE Atlantic marine hot spots. In such rapidly warming ocean regions, benthic and pelagic habitats become more suitable to tropical/subtropical megafauna species, allowing for a poleward expansion of their latitudinal distribution. The spatial extent of these changes seem to vary from species to species, but in subtropical/temperate transition regions they contribute to modifications in megafauna assemblages, gradually becoming dominated by invading warm-water species, therefore more tropicalised. We looked for signs of these changes in catches of multispecies fisheries conducted historically off South America and South Africa. Because these catches include varying abundances of different target and non-target species over time, they could carry signs of change in the regional fish and shellfish assemblages that fishers have long relied on.

We started by analysing catches of over 29,000 multispecies demersal fishing operations conducted in the Brazilian Meridional Margin (SW Atlantic) between 2000 and 2019 and monitored at the fishing harbours of Santa Catarina, Brazil. The region (c. 20°S to 34°S) encompasses a biogeographical subtropical/warm temperate fauna transition zone highly influenced by the dynamics of the Brazil Current, a western boundary current that flows southwards along the shelf break and slope carrying generally warm tropical waters. At approximately 38°S, the Brazil Current collides with cold sub-Antarctic waters carried northwards by the Malvinas Current, forming the Brazil-Malvinas Confluence (Fig. 1). This feature contains important environmental gradients, which are also noted on shelf waters off northern Argentina, Uruguay and southern Brazil. Since its early development in the 1960s, demersal fisheries operations off southern Brazil have been sustained by megafauna communities influenced by this dynamic oceanographic scenario, economically thriving from the catch of assorted subtropical and warm-temperate fish, crustaceans and cephalopod species. In the past decades, however, a poleward displacement of wind patterns over the South Atlantic has led to a southward expansion of the Brazil Current’s path, and displacement of Brazil-Malvinas Confluence (0.6-0.9° latitude per decade). Under the warming conditions promoted by a stronger influence of the Brazil Current, it was expected that subtropical species would have become more common on the Brazilian Meridional Margin and therefore more abundant in multispecies commercial catches. A previous study conducted by Ignacio Gianelly, Alberto Piola and others in 2019 provided important evidence for such process taking place since the 1980’s further south, at the Argentinian-Uruguayan Common Fishing Zone.

We used available global compilations of species thermal preferences to assign mean ‘optimum’ temperatures for each of 78 species recorded in the catches. Following a procedure first described by William Cheung, Reg Watson and Daniel Pauly in 2013, we used these optimum temperatures to calculate annual ‘mean temperatures of the catches’ (MTC), an index of aggregated thermal affinities of species contained in the catches. Our MTC time series showed a sharp increasing trend from 2012 onwards, significantly explained by increasing sea bottom temperatures and the transport volumes of the Brazil Current. Applying spatial and temporal community analyses we demonstrated that the MTC positive trend derived from biomass losses of cold-water species and gains of warm-water species in the catches, consistent with a general process of tropicalization of demersal megafauna off southern Brazil during the analysed period (Fig. 2). A few species had a particularly important role in this process including the Argentine croaker (*Umbrina canosai*), the Argentine hake (*Merluccius hubbsi*), the codling (*Urophycis mystacea*) and the monkfish (*Lophius gastrophysus*), all cold-

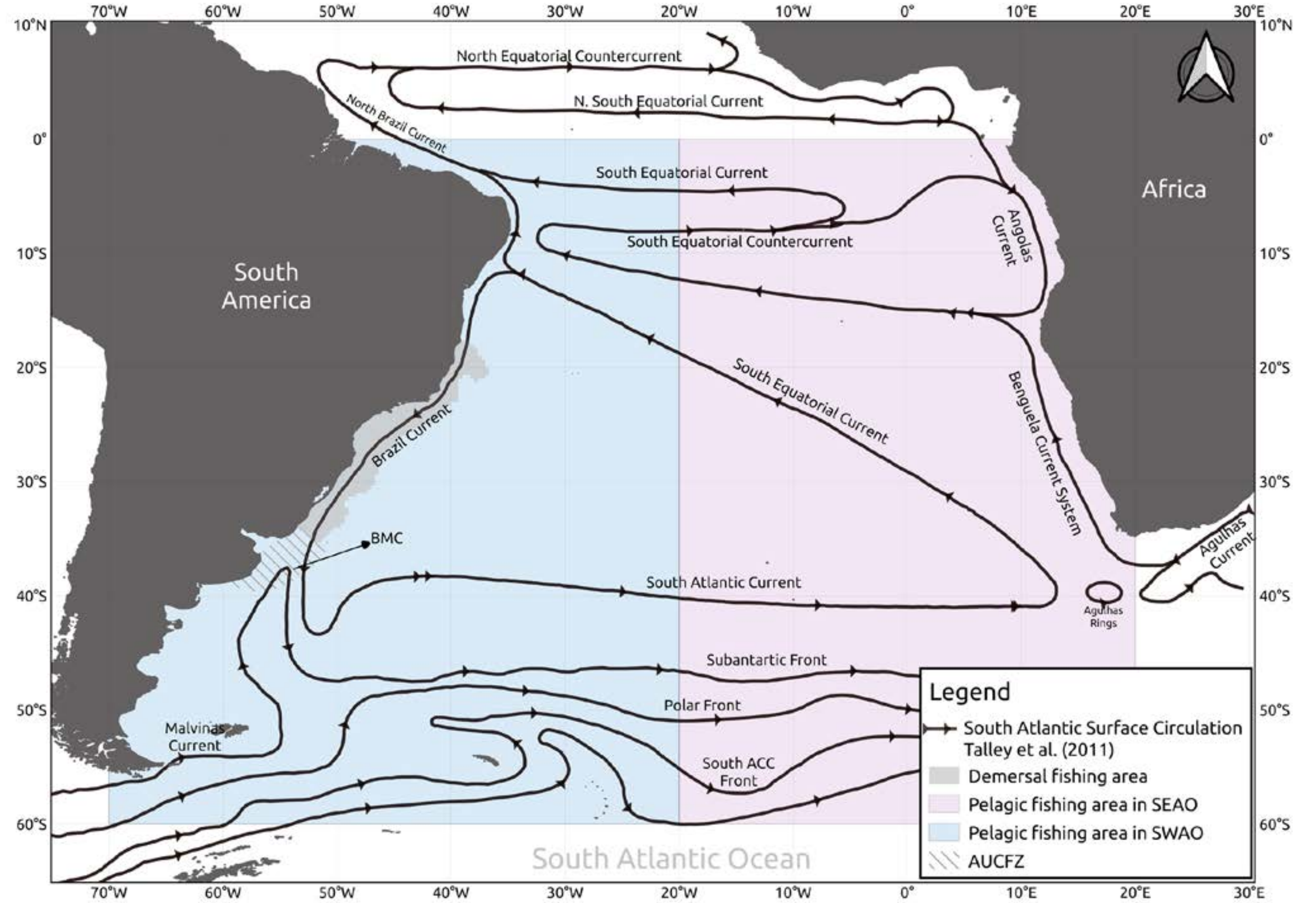


Figure 1: South Atlantic Ocean with schematic view of surface circulation. Also indicated are the study areas of demersal and pelagic fishing time series. BMC: Brazil-Malvinas Confluence; AUCFZ: Argentinian-Uruguayan Common Fishing Zone.

water species that have become scarcer in the catches and counterbalanced by increasing catches of the warm-water whitemouth croaker (*Micropogonias furnieri*), grey triggerfish (*Balistes capriscus*), the spotted pink shrimp (*Penaeus brasiliensis*) and others. None of these are 'invading' species in the region, but subtropical species that seem to have become more available to fisheries than they used to be.

Similar analytical approaches have been applied to the pelagic line fisheries for sharks, tuna and tuna-like species ,this time on both the SW and SE Atlantic regions. Time series of catches originated from historical records of the International Commission for the Conservation of Atlantic Tunas (ICCAT) between 1978 and 2018. Because these are highly migratory fish that can cover vast areas of the South Atlantic within the annual period, we had to consider much broader areas to compile both catches and sea surface temperatures. Yet we also found that annual MTC increased continuously on both sides of the South Atlantic during the studied period, and these trends were explained by increasing sea surface temperatures. Increasing MTC rates, however, were considerably low when compared to the ones observed in the demersal fisheries, and higher in the SW Atlantic than in the SE Atlantic. It is plausible that by being so mobile and having the capability to thermo-regulate, these large pelagic predators may find mechanisms to better assimilate environmental variability than demersal species. Also, although most species present in the catches occurred in both SW and SE regions where hot spots have been delineated, the associated ocean circulation processes differ greatly as well as, potentially, the mechanistic links between warming and biological responses. We found that biomass losses of the 'cold-water' albacore (*Thunnus alalunga*) in the catches had an important role in modulating MTC on both sides of the South Atlantic, being counterbalanced by catches of species with higher affinity for warm waters, chiefly the skipjack tuna (*Katswonus pelamis*), serra spanish mackerel (*Scomberomorus brasiliensis*), swordfish (*Xyphias gladius*), bigeye tuna (*Thunnus obesus*), yellowfin tuna (*Thunnus albacares*) and king mackerel (*Scomberomorus cavalla*). We are now concentrating on modelling abundance indices of some of these species to look into temperature-related temporal variability at the population level.

After the global study published by William Cheung and partners in 2013, similar analyses of commercial catches have evidenced tropicalisation scenarios in different regions around the world. Yet often this evidence can be hindered by regional factors unrelated to climate change, including fishing economic strategies, overfishing and management actions. Efforts must be done to measure/reduce their interference. Notwithstanding this, historical catch data have proven to be an effective proxy to global climate effects on marine ecosystems regionally, with the advantage of further signalling to future changes in the economic performance of current of fishing regimes. How will the fishing industry in these areas of the South Atlantic Ocean adapt to changes in the availability of traditional and non-traditional targets? Which fishing economic strategies will no longer be viable and which ones may emerge to explore expanding stocks of subtropical species? What adaptive measures can be incorporated in fishing management regimes (both national and transnational) to attain ecological and economic objectives in the coming decades? These are critical questions that will guide further applications and improvements of these analytical approaches in the South Atlantic and other ocean regions.

Key references

Cheung, W.L., Watson. R. & Pauly. D. Signature of ocean warming in global fisheries catch. Nature 497, 365-369, doi:10.1038/nature12156 (2013).

Franco. B. et al. Climate change impacts on the atmospheric circulation. ocean. and fisheries in the southwest South Atlantic Ocean: a review. Climatic Change https://doi.org/10.1007/s10584-020-02783-6 (2020).

Gianelli, I., Ortega, L., Marín, Y., Piola. A.R. & Defeo. O. Evidence of ocean warming in Uruguay's fisheries landings: the mean temperature of the catch approach. Mar. Ecol. Prog. Ser. 625, 115-125, ttps://doi.org/10.3354/meps13035 (2019).

Hobday, A.J. & Pecl, G.T. Identification of global marine hotspots: sentinels for change and vanguards for adaptation action. Rev Fish Biol Fisheries, 24, 415–425. https://doi.org/10.1007/s11160-013-9326-6 (2014).

Piola, A.R. et al. Physical Oceanography of the SW Atlantic Shelf: A Review in Plankton Ecology of the Southwestern Atlantic (eds. Hoffmeyer, M.S. et al.) 37 – 56 (Springer, 2018).

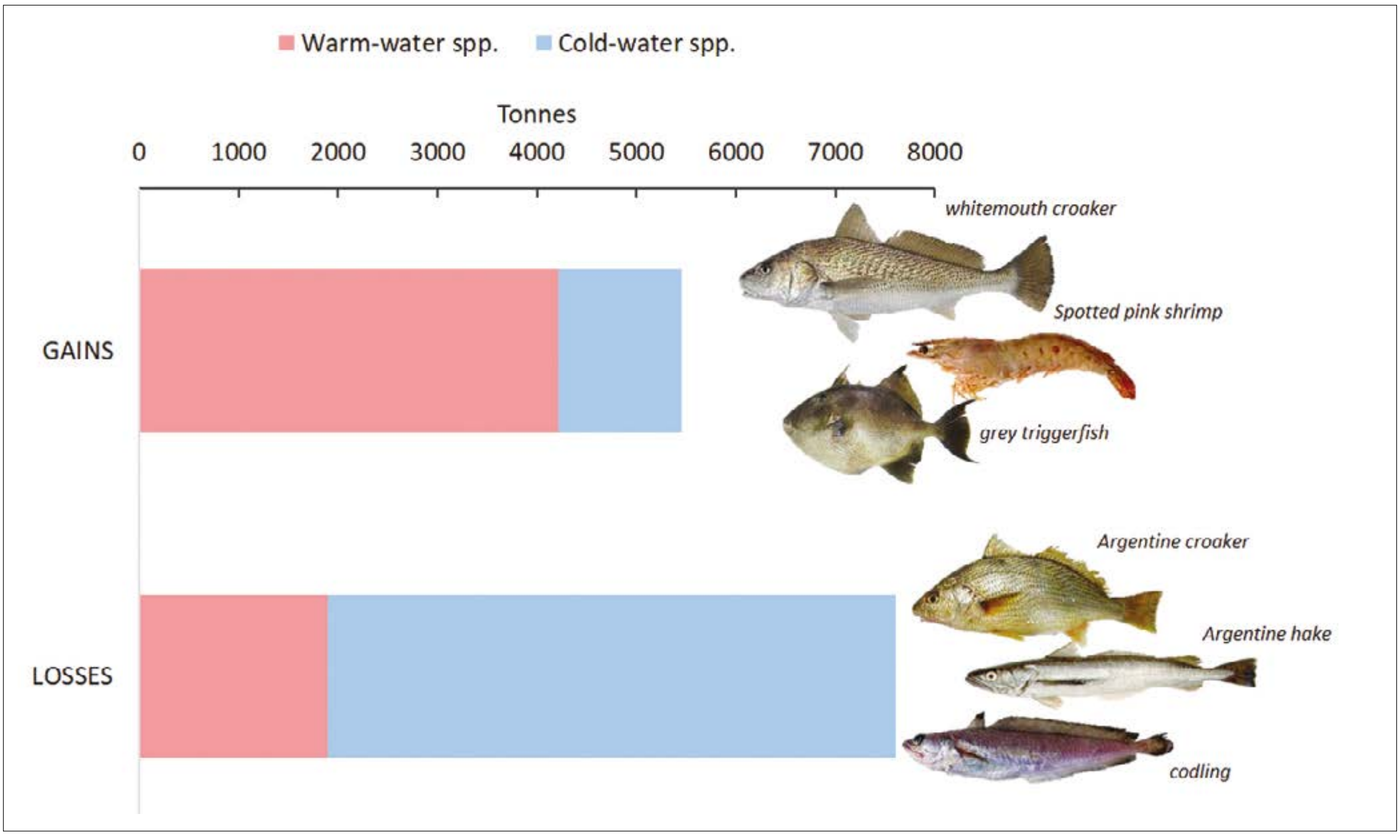


Figure 2: Average biomass gains and losses in the demersal catches in the Brazilian Meridional Margin between 2000-2002 and 2017-2019. Biomass gains and losses are dominated by warm- and cold-water species, respectively. Fish images: www.fishbase.org, www.pt.wikipedia.org , INIDEP, www.demersais.furg.br , Luciano Fischer, FAO, https://pt.frwiki.wiki/

Looking into the past to understand the future: the fate of cold-water corals in a changing ocean

Dierk Hebbeln & Rodrigo da Costa Portilho-Ramos (MARUM/University of Bremen)

Long seen as a desert almost barren of life, the deep sea is now known to host a variety of fascinating and diverse ecosystems. Among these, reefs and mounds formed by framework-forming scleractinian cold-water corals (CWC) stand out for their biodiversity and their capacity to shape the seafloor. By regulating food web structure and cycling nutrients, offering nurseries for fish and by supporting an impressive biodiversity, CWC reefs provide significant ecosystem services. However, CWCs are also vulnerable ecosystems, hence future environmental changes induced by continuous anthropogenic CO_2 emission resulting in ocean warming, acidification and deoxygenation, as well as changes in food variability, may pose severe consequences to these ecosystems – even when some of these changes might reach the deep sea only damped. Thus, to understand how CWC ecosystems might respond to environmental changes in the future is of pivotal importance to enable knowledge-guided management decisions and mitigation policies to protect these ecosystems and their services for society.

Assessing the fate of CWCs under ongoing and future environmental change is difficult, mostly because of a complete lack of field observations documenting a local/regional demise of CWCs other than those due to direct physical impact, such as bottom trawling. However, Ecological Niche Factor Analysis (ENFA) revealed some thresholds for individual physical parameters, without resolving regional varying thresholds on population scales and without allowing inferences on multi-stressor interactions. In addition, assessing the role of (commonly small-scale) dynamic features usually

is hampered by the limited resolution of the global database. Furthermore, manipulative experiments led to contradictory results due to the complexity of physiological processes, genotypes and geographic distribution, species-specific ecological preferences and tolerances as well as their time-dependent response to multi-stressor exposure.

Luckily, due to their carbonate skeleton, CWC get preserved as fossils in the geological record allowing to trace their fate through time and, thus, to analyse their response to past climatic changes. Early investigations on sediment cores taken from coral mounds used radiocarbon and U/Th dating to identify periods when CWC developed in a specific region. These studies revealed a cyclic occurrence of CWC at most investigated sites, with periods of flourishing reefs alternating with periods marked by the absence of corals. For instance, off Ireland CWC were largely restricted to interglacial periods, while in the wider Gulf of Cádiz they mainly occurred during glacial periods (Fig. 1), with these observations pointing to a climate control on their occurrence. This approach can be combined with conventional paleoceanographic tools to reconstruct the environmental conditions in the past and, aligning these reconstructions with the coral records, allows identification of the key environmental drivers that were able to push CWC ecosystems beyond a threshold, causing their demise when conditions deteriorated but also their reoccurrence when conditions improved. Depending on the applied datasets, individual regional studies pointed to various cause-and-effect relationships controlling the proliferation of CWC through time.

In a recent iAtlantic publication, Rodrigo Portilho-Ramos and colleagues compared, for the first time, records from six different sites from the North Atlantic and the Mediterranean Sea by applying the same paleoceanographic proxies to variable past CWC records over the last 20,000 years, including the last major global warming event at the end of the last glaciation. The six paleo-records documented coral demises as well as reoccurrences, which were related to changes in bottom-water temperature, salinity, oxygenation and hydrodynamics, and in export production. One of the threats for CWC, ocean acidification, could not be addressed in this study, as on the timescale considered – the last 20,000 years – no comparable setting with atmospheric CO_2 contents of >400 ppm and its impact on ocean chemistry occurred. Thus, the impact of a more acidified ocean on CWC in the future can probably only be investigated by laboratory studies.

Statistical analyses of the proxy data in combination with coral occurrence or absence at the six North Atlantic sites indicated food supply as the most important driver for the CWC. For CWC, food supply is controlled by the vertical flux fueled by export production from the surface ocean and by the lateral flux advected to the coral by the local/regional hydrodynamic regime, with the latter seemingly playing the most important role. The regional current system and internal tides interacting with the local topography (e.g., the coral mounds) provide a huge amount of energy enabling an efficient lateral transport of food particles to the CWC. In most cases documented at the six sites, the demise or reoccurrence of CWC was bound to major changes in the hydrodynamic conditions with some impacts of changing export productivity or changing bottom-water oxygenation. Interestingly, changes in bottom water temperature seem to play no major role in the long-term development of CWC through the last major global warming event, despite the prominent role given to temperature by ENFA. This is probably due to the fact that the temperature range tolerated by the CWC is hardly exceeded in the intermediate waters of the tropical to temperate regions the CWC live in.

The observation that food supply plays a key role for the proliferation of CWC points to upcoming problems as projected decreases of primary productivity will most likely have negative effects for the CWC. However, as bottom-water hydrodynamics seem to be even more important – even for concentrating less exported food towards the CWC – this makes any projections about the fate of CWC in a changing ocean in the future extremely difficult. While, for instance, future temperature changes can be modelled reasonably well, bottom-water hydrodynamics that depend on the interaction of ocean currents, internal tides and local seafloor topography cannot yet be projected with nearly enough accuracy for what is needed. Thus, a key challenge for improving our abilities to develop effective management strategies for CWC ecosystems lies in the substantial improvement of ocean models down to the CWC-reef scale.

Read the full article: Portilho-Ramos et al. (2022) Major environmental drivers determining life and death of cold-water corals through time. PLoS Biol 20(5): e3001628. DOI: 10.1371/journal.pbio.3001628

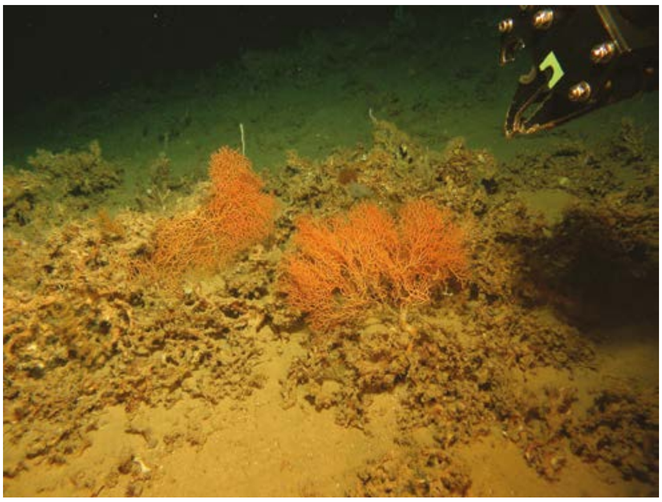


Figure 1: Thriving cold-water corals off Ireland (main image, left) and fossil coral accumulations off Morocco. Approx. 20,000 years ago, this pattern was reversed, with living corals off Morocco and none off Ireland. Intermittent growth of cold-water corals on millennial time scales has been a common pattern in the North Atlantic in the past. Photos: © MARUM, Univ. Bremen.

Using 3D photogrammetry to study tissue regeneration in *Dendrophyllia cornigera* and how it is affected by multiple stressors

by Álvaro Romo Molina-Prados[1], Cristina Gutiérrez-Zárate[3,4], Alfredo Veiga[2], Andrea Gori[4], Juancho Movilla[3], Marta Álvarez[3] & Covadonga Orejas[3]

1. Universidad de Santiago de Compostela; 2. Aquarium finisterrae; 3. IEO-CSIC; 4. Universitat de Barcelona

Dendrophyllia cornigera is a scleractinian cold-water coral (CWC), with a skeleton of calcium carbonate covered by a characteristic yellow tissue called coenosarc, which covers the skeleton and connects the polyps of the colony. This tissue may suffer damage from natural phenomena, diseases, competition with other species or by anthropogenic activities such as direct mechanical impacts from deep-sea fishing. During these activities, corals may be dragged or dislodged from the substrate, or damaged with lesions resulting in the loss of tissue and skeleton exposure. To repair these lesions, corals can produce new tissue from the existing tissue surrounding the lesion.

Today, most of studies of tissue regeneration are focused on tropical shallow-water corals, which are more accessible than cold-water corals for *in situ* analyses. In these studies, researchers observed that tissue regeneration varies among species and is affected by the size and form of the lesion. In aquaria experiments to test the effects of ocean acidification on coral, scientists observed that acidification negatively affects tissue regeneration rates in the corals *Porites* sp., *Favia favus*, *Acropora eurystoma* and *Stylophora pistillata*. However, far as we know there are only two studies conducted on CWCs, and both species – *Gersemia rubiformis* and *Lophelia pertusa* – revealed fast regeneration rates.

Previous studies showed that changes in the environmental conditions might affect ecophysiological processes (i.e. skeletal growth, respiration or excretion) of some species of CWCs. It might be possible that climate change-related environmental impacts could also affect the ability of *D. cornigera* to regenerate tissue. The main objective of our study is to analyse the tissue regeneration of *D. cornigera* and determine how synergies of stressors arising from climate change (sea water warming, deoxygenation and acidification) might affect it.

This study is being conducted at the Aquarium finisterrae (A Coruña, NW Spain), where eight different treatments were created to simulate all the possible combinations (from current conditions to the most catastrophic scenario, IPCC AR5 RCP8.5) of predicted climate change scenarios for temperature, dissolved oxygen concentration and pH. To study tissue regeneration, we create a wound on the coral nubbin tissue – specifically a circular wound made with a grinding stone that removes a small portion of the tissue and expose the skeleton. Several methods for creating this wound were explored, for instance using an air pick or by burning, but the most efficient method was with a grinding stone of 4 mm diameter. With this method we avoided affecting the skeleton too much, which is especially relevant in the case of the smaller nubbins. After causing the wound, the coral is monitored for one month, and the wound and regenerated area measured once every week using photogrammetry. To measure the area of the lesion as well as the regenerated tissue, we will process the digital photogrammetric images and generate 3D spatial data.

To perform the 3D reconstruction, we designed and created a setup that allows us to obtain photos of the nubbins in different positions. The set up consists of a 18 L aquarium, and a 3D-printed structure to hold and rotate the nubbin (Fig. 1). This system has two elements: the first element is located below the tank and has a disc with four attached magnets that rotates thanks to an Arduino minicomputer, which is connected to a rotation mechanism. The second element is placed on the floor of the aquarium and is equipped with another set of four magnets that connects to the first element, allowing the rotation of the structure that holds the nubbin. To perform the 3D reconstruction (using the software Agisoft Metashape Professional) through acquisition of images, eight markers are painted on the structure holding the nubbin, and a green background is used to obtain better contrast. Aquarium lighting consists of three LEDs: two on the sides and one on top of the aquarium. Finally, we connected the camera shutter to the Arduino, which allows us to select the number of shots per rotation and the interval between shots. The Arduino rotates the structure holding the nubbin and takes all the photos automatically (Fig. 2) Once all images have been captured, the images are analysed by the photogrammetric processing software Agisoft Metashape Professional to generate a 3D model (Fig. 3) where the wound area can be measured.

We are currently finishing the acclimation of the *D. cornigera* nubbins to the different treatments. In few weeks we will create the wound on the nubbins and conduct the first round of image acquisition and subsequent 3D reconstruction. A month later a second 3D reconstruction will be performed, which will reveal the tissue regeneration rate of *D. cornigera* under different environmental scenarios. Stay tuned for updates from our aquaria team!

Acknowledgements: We would like to give our thanks to the people of Museos Científicos Coruñeses, especially Rodrigo Pérez, for the design and setup of the 3D reconstruction system, and to Leo Domínguez, Fabian Gerpe, Alberto Rodríguez and Noelia Arias for their input on the aquaria setup.

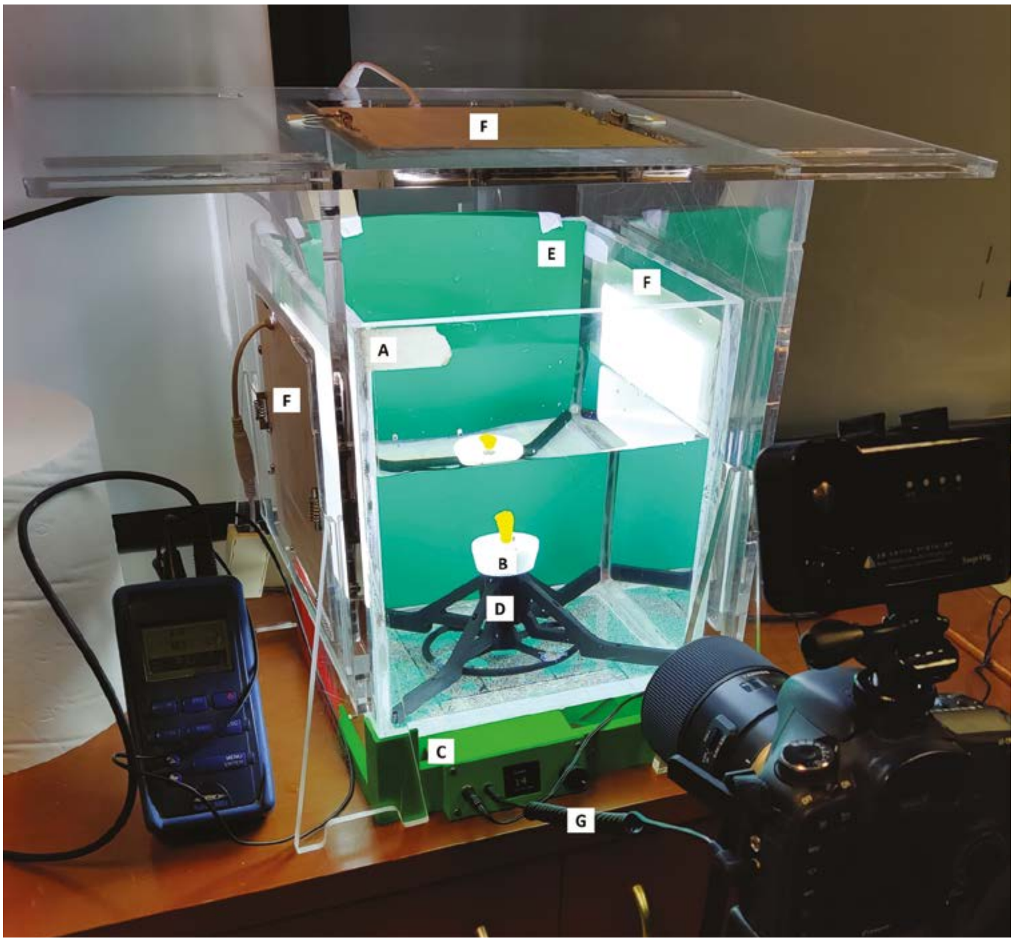
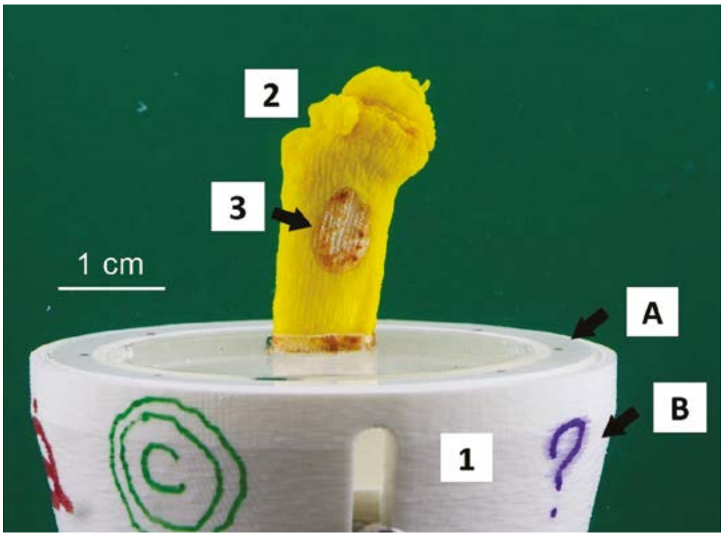


Figure 1: Lab setup to perform the photogrammetric analyses:

A. 18 L Methacrylate aquarium.
B. 3D-printed structure to hold and rotate the nubbin.
C. Arduino minicomputer.
D. Part of the rotation system inside the aquarium.
E. Green background.
F. 3 LED lights.
G. Connection between the camera shutter and the Arduino.



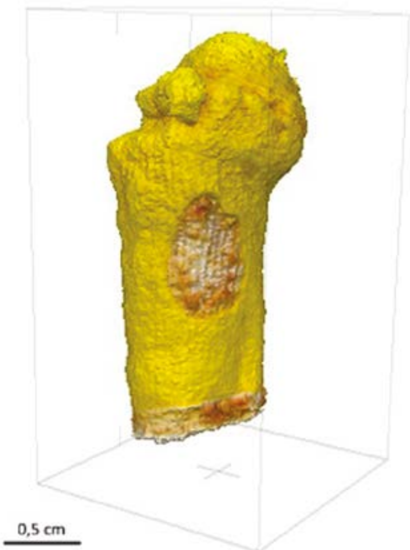


Figure 2 (above left): Example of the photos taken during the process. (1) The structure that rotates and hold the coral nubbin, with eight markers (A) and six symbols (B) to facilitate the image recognising by the software for the 3D reconstruction. (2) Coral nubbin. (3) Example of a wound: loss of tissue and exposure of skeleton.
Figure 3 (above right): Example of a 3D reconstruction of a D. cornigera *nubbin with a wound. For this reconstruction 30 photos have been used.*

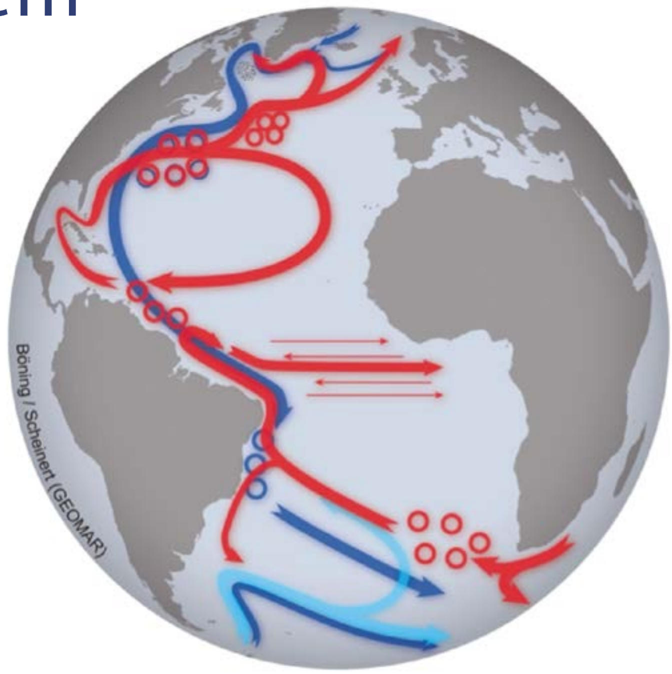
New insights into changes in the Atlantic current system

By Arne Biastoch, GEOMAR

A gigantic system of ocean currents in the Atlantic Ocean constantly carries water from north to south and back again. This circulation is subject to strong fluctuations and has weakened since the 1990s. Since it also transports large amounts of heat, this weakening can also have consequences for the Earth's climate, and experts are debating whether the changes observed since the 90s can be attributed to climate change. For the future ocean, model simulations predict such an influence with a high degree of probability. An international team involving iAtlantic's Arne Biastoch (GEOMAR) has analysed in more detail how this oceanic circulation system changed during recent decades, and show that the speed of the current varied in a rhythm of decades. However, the look into the past does not yet answer the question whether climate change is causing the recent slowdown.

Among the biggest climate drivers worldwide are the powerful ocean currents that constantly circulate through the Atlantic Ocean. South and east of Greenland, cold water – heavy due to its high salinity – sinks to the deep ocean and moves southward. As a counter movement, warm water flows northwards from the tropics in the surface ocean. Experts call this circulation, which spreads across the entire ocean, the Atlantic Meridional Overturning Circulation (AMOC). The Gulf Stream, which brings heat from the Gulf of Mexico across the Atlantic to Europe and provides Europeans with a mild climate, is part of this circulation. In the geographic latitudes where this conveyor belt moves particularly fast, it transports almost twenty times more water in one second than all the rivers in the world carry into the sea in the same time.

New research by a team of experts from Germany, Great Britain, France and the United States of America shows that the strength of the North Atlantic circulation changes in a natural decadal rhythm. This study is an important contribution to the much-discussed question of whether the slowdown of the AMOC, which has been happening since the late 1990s, can be attributed to human-induced climate change. Because water and associated heat transports are crucial for our climate, scientists around the world are very interested in this information. "Changes in the AMOC have been observed for some time. But the data were uncertain," explains Arne Biastoch, a coauthor of this new study. "In the current publication, we have brought together findings of many different research studies, including many measurements and results from computer models." The analyses show that the AMOC has weakened and strengthened repeatedly over the past decades. This appears to be mainly part of a natural change that recurs over several decades. "However, on the basis of the results so far, we are currently unable to identify whether there is already an underlying longer-term weakening. All climate models predict such a weakening in the future as a result of human-induced climate change," Arne Biastoch emphasises.



The Atlantic Meridional Overturning Circulation (AMOC) covers the entire Atlantic Ocean. Warm (near-surface) currents are shown in red, cold deep currents in blue. The small circles show areas with strong eddy activity. The dotted area in the Labrador Sea shows the area with deep convection, where cooled water masses sink to depths of several kilometres. Graphic: C. Böning/M. Scheinert, GEOMAR

At GEOMAR, Arne's team works with the complex computer model VIKING20X, which simulates currents and hydrography in the Atlantic. It takes hundreds of parameters into account to represent the gigantic circulation in the North Atlantic. Thanks to enormous computing power, VIKING20X now calculates the AMOC on a grid of a few kilometres. This means that even the numerous small eddies in which the gigantic current moves forward are captured. In iAtlantic, VIKING20X is used to expand the spatio-temporal range of naturally limited observations, to drive ultra-high-resolution regional models, and to provide the input for Lagrangian dispersal studies on deep-sea organisms and ecosystems which allow us to better understand ecosystem connectivity.

Read the full article:

Jackson, L.C., Biastoch, A., Buckley, M.W., Desbruyères, D.G., Frajka-Williams, E., Moat, B., Robson, J. (2022) The evolution of the North Atlantic AMOC since 1980. Nature Reviews Earth & Environment, DOI: 10.1038/s43017-022-00263-2

Disentangling the last millennia of environmental change offshore Cabo Verde

By Irene Pérez-Rodríguez[1], Thor H. Hansteen[2], Julie C. Schindlbeck-Belo[2], Dirk Nürnberg[2], Steffen Kutterolf[2], Veerle Huvenne[3,4], Colin Devey[2], Erik Simon-Lledó[3], Susan Evans[3], Kelsey Archer Barnhill[5], Beatriz Vinha[6], Andrea Gori[7], Ángela Mosquera Giménez[8] & Covadonga Orejas[9,4]

1. Centro Oceanográfico de Vigo, Instituto Español de Oceanografía, Spain

2. GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany

3. National Oceanography Centre, Southampton, United Kingdom

4. Hanse-Wissenschaftskolleg Institute for Advanced Study, Germany

5. School of GeoSciences, University of Edinburgh, UK

6. Department of Biological and Environmental Sciences and Technologies, Università del Salento, Italy

7. Department of Evolutionary Biology, Ecology and Environmental Sciences, Universitat de Barcelona, Spain

8. Centro Oceanográfico de Canarias, Instituto Español de Oceanografía, IEO-CSIC, Santa Cruz de Tenerife, Spain

9. Centro Oceanográfico de Gijón, Instituto Español de Oceanografía, IEO-CSIC, Gijón, Spain

The archipelago of Cabo Verde is in a complex oceanographic area, influenced by multiple atmospheric, hydrodynamic and geologic processes, which act at different scales (Fig. 1). From an oceanographic point of view, this area lies between the North Equatorial Current to the North and the North Equatorial Counter Current to the South. Additionally, the Cabo Verde Frontal Zone separates the North Atlantic Central Water from the South Atlantic Central Water. It is also marginally affected by two different areas of upwelling: the Guinea Dome and the coastal upwelling area off north-west Africa. There are additional features typical of the Cabo Verde area, such as the Sahara dust input (influenced by the regional wind pattern), volcanic activity and ash deposition, which affect the environmental characteristics of the water and the regional ecosystems. Due to the confluence of these factors, the basin is presumably sensitive enough to record environmental changes through time caused by perturbations of one or several of these processes. Through this research, we aim to contribute to the understanding of the past oceanographic fluctuations during the last millennia by studying sediment cores, which function as great archives of climate and environmental changes.

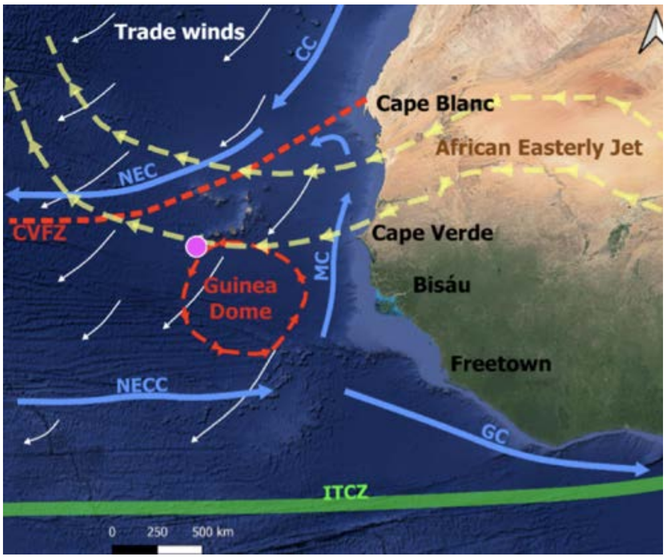


Figure 1: Oceanography and wind pattern of the Cabo Verde Archipelago represented schematically. Main surface currents are shown as blue arrows: CC, Canary Current; NEC, North Equatorial Current; NECC, North Equatorial Counter Current; GC, Guinea Current; MC, Mauritanian Current. Cabo Verde Frontal Zone (CVFZ) and Guinea Dome are indicated as red dotted lines. White arrows illustrate trade winds, yellow arrows the African Easterly Jet and the green line represents the Intertropical Convergence Zone (ITCZ). Pink dot shows the location of the iMirabilis2 coring sites. Base map from Google Maps, 2022.

GEOMAR has previous experience studying the sediments from this area. They retrieved 28 gravity cores around the archipelago during the RV *Meteor* M80/3 cruise, which took place during December 2009 to February 2010. These cores were several meters long, and some of them go back to ca. 150,000 years. However, due to the sampling technique, some of the surface sediments could have been lost and, therefore, the most recent environmental history may be missing. IEO-CSIC has recently joined GEOMAR in deciphering the information that the sediments can reveal, and hopefully fill this information gap. During the iMirabilis2 cruise, which took place on board the Spanish RV *Sarmiento de Gamboa* in July-August 2021, multicorer and boxcorer sampling was conducted to help fill these gaps, therefore cores were collected in some of the sites previously cored by GEOMAR. Multicorer and box corer supply shorter cores (40 cm was the maximum length accomplished) but they do preserve the uppermost sediments. In this way, we hopefully can overlap the information provided by both set of cores to obtain a continuous palaeoceanographic history, from the present to more than a 100,000 years in the past.

In order to compare results from the two expeditions and the different gears, GEOMAR and IEO-CSIC applied the same methodology to analyse the cores. Firstly, cores were analysed by X-ray fluorescence scanning. This technique has the capability to acquire, in a semi-quantitative and

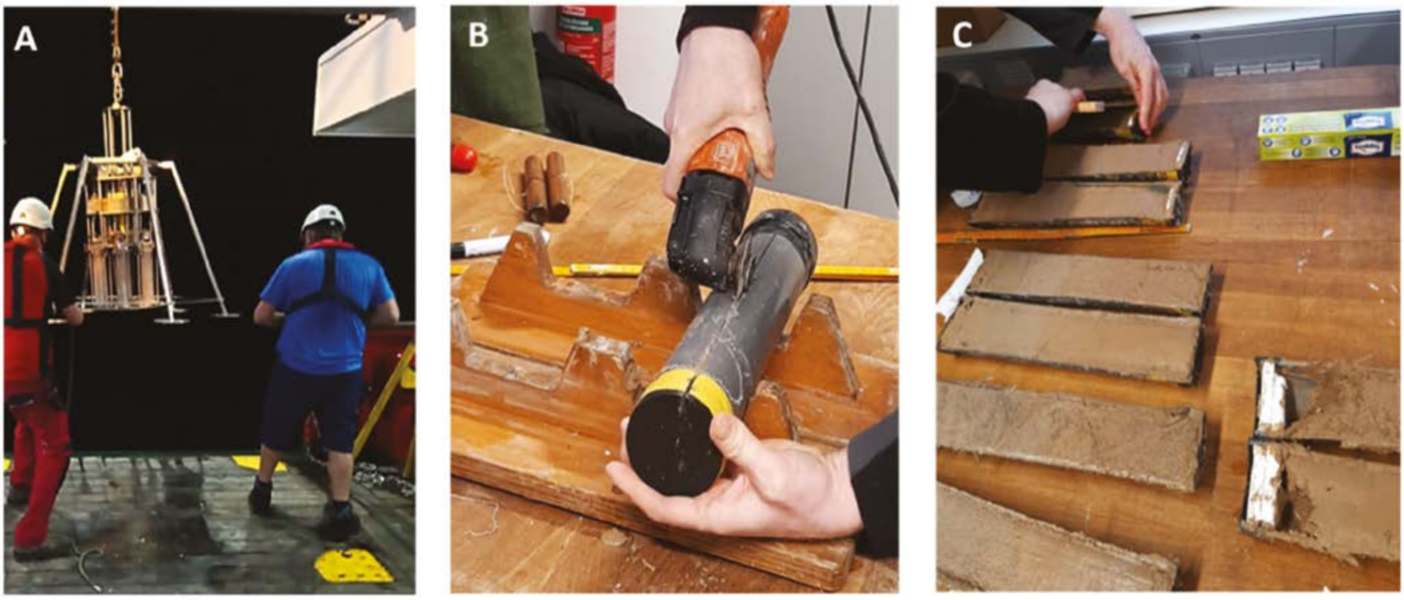
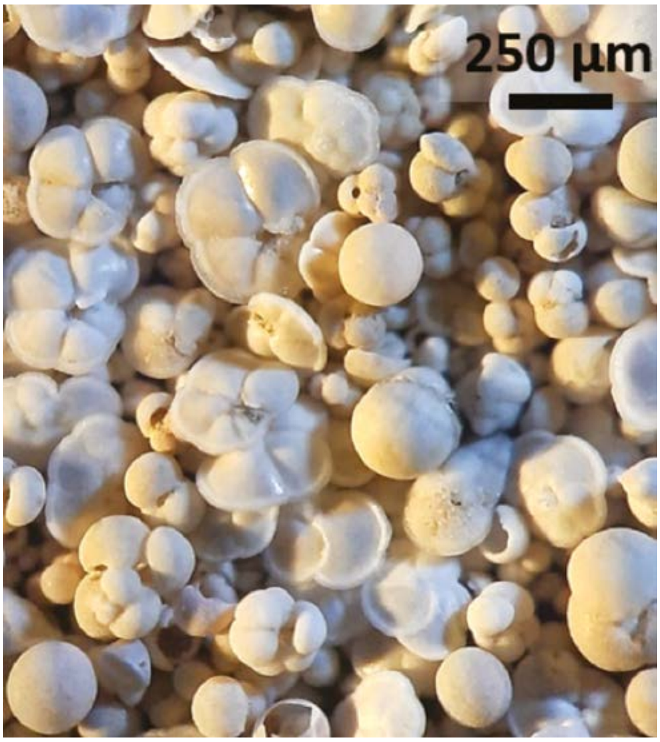


Figure 2: A) Multicore deployment during the iMirabilis2 cruise, B) core opening at the GEOMAR facilities, C) smoothing the surface of the cores with a spatula after splitting them into two halves.

continuous manner, the chemical elements throughout the core, from aluminium to uranium. The interpretation of these geochemical results is frequently used to infer past environmental processes such as aeolian dust/terrigenous input, hinterland aridity or humidity, organic productivity or volcanic activity. Secondly, GEOMAR and IEO-CSIC will perform geochemical analyses of the foraminifera carbonate tests (shells). These single-celled organisms (Fig. 3) belong to the Protista Kingdom and they usually secrete a resistant calcite or calcium carbonate test, which can be found abundantly in sediments. The chemistry of these shells reflects the composition of the seawater in which they calcify, so they are major proxies used to reconstruct the palaeoclimatic history, since they can provide data about temperature, salinity and the global ice volume of ancient water masses. Another advantage of looking at foraminifera is that different species inhabit distinct water depths or habitats; as a consequence, it is possible to reconstruct the ocean properties at different depths within the water column.



Moreover, the volcanic ash content is being studied in both sets of cores to explore past volcanic eruptions. Major and minor elements of the volcanic glass shards found in the sediments will be analysed to characterise their composition, and thus to be able to link them to specific eruptions. Conspicuous ash layers were found in the GEOMAR gravity cores, but not in the shorter IEO-CSIC sediments. However, these later cores may still contain cryptotephra, which are sparse and distantly-sourced volcanic ashes that do not form visible layers but can provide valuable information from the perspective of the chronology and volcanic processes.

Following these methodologies, GEOMAR already obtained interesting results in the gravity cores, such as dramatic palaeoceanographic changes linked to the last glacial/interglacial transition, as well as identification and frequency of explosive volcanic eruptions. We expect that the newly collected cores, containing more recent sediments, will provide the missing piece of the environmental variability record of the last millennia from offshore Cabo Verde.

Figure 3: Foraminifera assemblage in one of the core samples from offshore Cabo Verde.

Wondering which deep-sea animals were spotted by ROV *Luso* offshore Cabo Verde?

By Beatriz Vinha, iAtlantic Fellow, University of Salento

If your answer is yes, you can now find out by checking the new species catalogue of the deep-sea benthic megafauna of Cabo Verde, based on observations from the iMirabilis2 expedition.

The species catalogue of the deep-sea benthic megafauna of the SW of Cabo Verde (eastern equatorial Atlantic) is now publicly available in Zenodo! This is based on observations with ROV Luso (EMPEC) during the iMirabilis2 expedition (Orejas et al., 2022), and is the first comprehensive deep-sea benthic species guide for the Cabo Verde archipelago.

In this catalogue we have identified, to the lowest possible taxonomic level, 237 morphospecies, including hard-bottom benthic megafauna, observed from 2,100 to 1,400 m water depth, as well as abyssal megafauna observed during ROV surveys at 3,500 m water depth.

The original idea behind this document was to aid the quantitative video analysis of the ROV data, but, overall, we hope that this photo catalogue will contribute new knowledge on the species present in this relatively unexplored region of the Atlantic, and that it will be a useful resource for other researchers working around NW Africa and in the equatorial Atlantic Ocean.

The final result presented in this catalogue is only possible due to the contributions and reviews of different experts, working along different areas of the Atlantic Ocean, who I would like to formally thank.

This is one of the first publicly available results from the iMirabilis2 expedition – expect more in the upcoming months, as the different teams continue to work on their datasets – and it already gives us new insights about the wonderful biodiversity of the Cabo Verde islands.

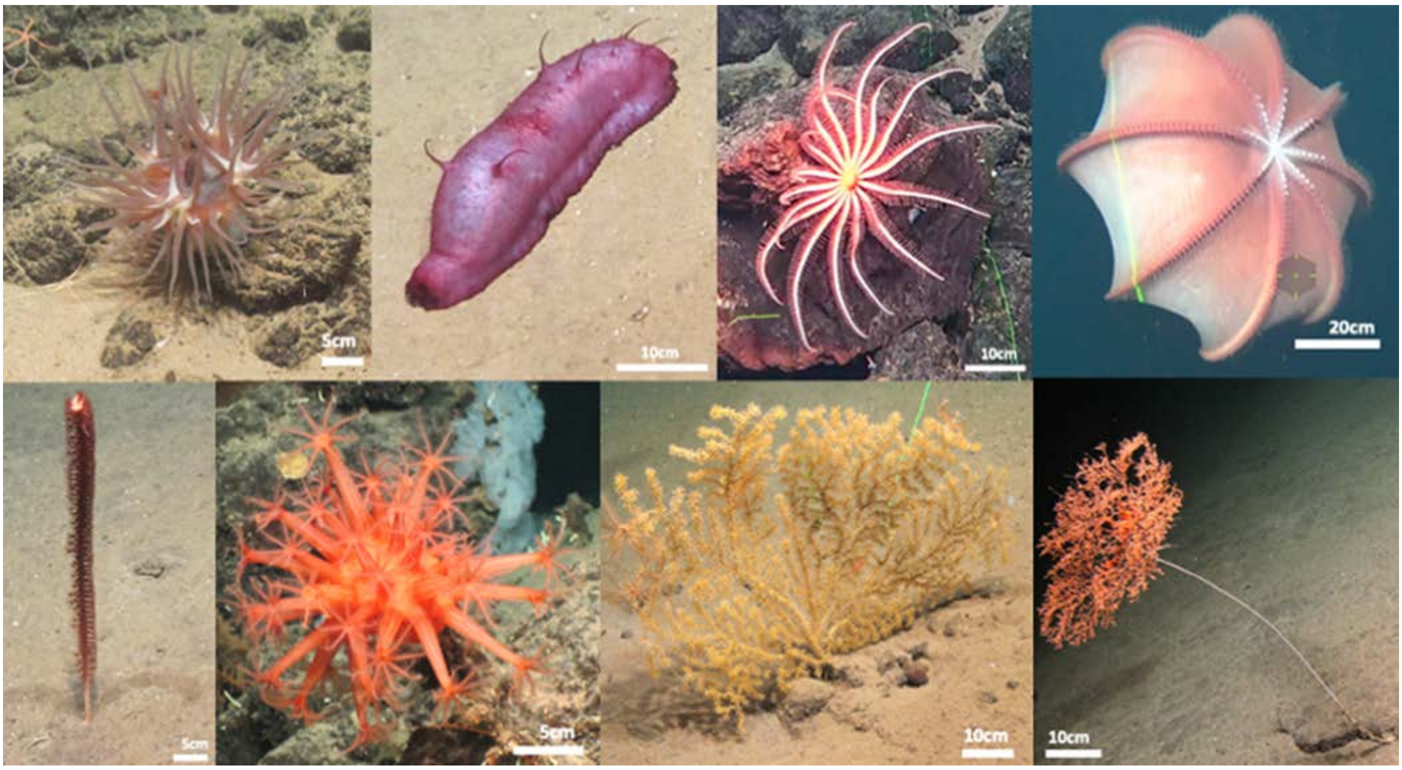
As our knowledge continues to expand about the deep-sea of Cabo Verde, I can already say that I am looking forward to seeing which new species will be added to this growing list.

You can now download the species catalogue and the iMirabilis2 expedition report using the following links:

Beatriz Vinha et al. (2022) Deep-sea benthic megafauna of Cabo Verde (Eastern Equatorial Atlantic Ocean) (Version 1). Zenodo. https://doi.org/10.5281/zenodo.6560869

Covadonga Orejas et al. (2022) Expedition report iMirabilis2 survey. Zenodo. https://doi.org/10.5281/zenodo.6352141

Images © iMirabilis2(IEO,CSIC)/EMPEC/iAtlantic project



The Atlantic Ocean landscape

A basin-wide cluster analysis of the Atlantic near-seafloor environment

Mia Schumacher[1], Veerle A.I. Huvenne[2], Colin Devey[1,3], Pedro Martínez Arbizu[3], Arne Biastoch[1] & Stefan Meinecke[4]

1. GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany

2. National Oceanography Centre, Southampton, UK

3. Kiel University, Kiel, Germany

4. Senckenberg am Meer, German Center for Marine Biodiversity Research (DZMB), Germany

5. RV Sonne, Briese Research, Briese Schiffahrts GmbH & Co.

Landscape maps based on multivariate cluster analyses provide an objective and comprehensive view on the (marine) environment. They can hence support decision-making regarding sustainable ocean resource handling and protection schemes. Across a large number of scales, input parameters and classification methods, numerous studies categorise the ocean into seascapes, hydro-morphological provinces or clusters. Many of them are regional, however, while only a few are on a basin scale.

The Atlantic Seabed Areas map presents the result of an automated cluster analysis of the Atlantic seafloor environment, based on eight global datasets: Bathymetry, sediment thickness, POC flux, salinity, dissolved oxygen, temperature, current velocity, and phytoplankton abundance in surface waters along with seasonal variabilities. Figure 1 shows the nine seabed areas (SBAs) that we've found that portray the Atlantic seafloor, whereby the grey areas are cells with a classification probability of less than 98%. The legend outlines the SBA's major characteristics which were interpreted using boxplots and further literature. Some SBAs have a clear geological and geomorphological nature, while others are defined by a mixture of topographical and water characteristics.

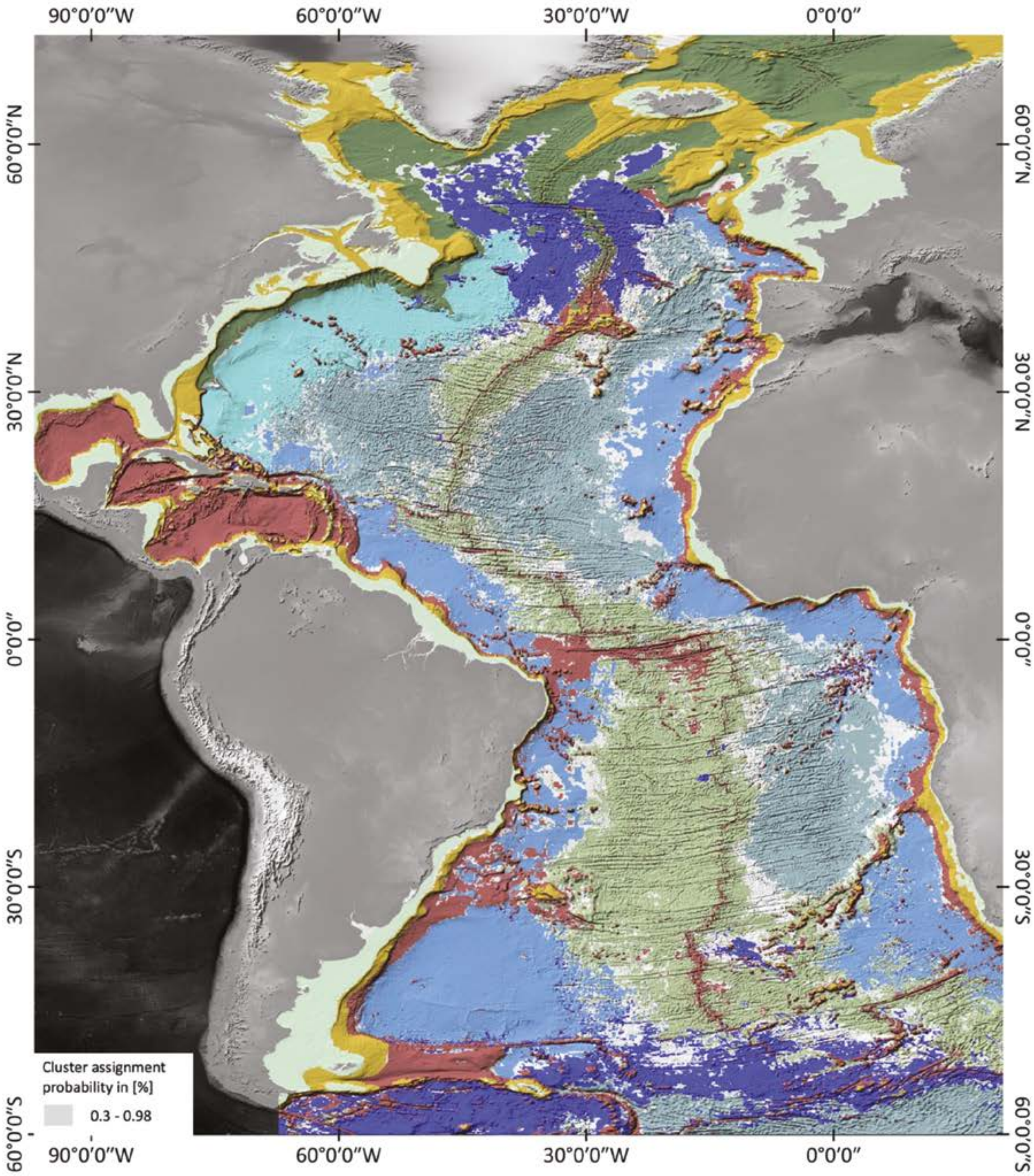
To demonstrate the potential use of the marine landscape map for marine spatial planning purposes, we further mapped out local SBA diversity using a patch richness index, originally developed in landscape ecology (Fig. 2). It identifies areas of high landscape diversity, and is a practical way of defining potential areas of interest, e.g., for designation as protected areas, or for further research.

We found that some of the iAtlantic study areas are well filled with landscape diversity highlights (see bright spots on Fig. 2), but others – especially those in the North Atlantic – are not, and many highlights also lie outside the study areas. This indicates the use of such analyses to automatically find potentially vulnerable or sensitive areas.

A key component of iAtlantic's work is to map, at nested scales, the present ecosystem status of deep and open-ocean ecosystems in the Atlantic. For this we need to better understand the relationship between ecosystem distribution and the physical environment across the Atlantic; have a clear picture of the 3D structure of key ecosystems at regional and local scale; and identify the main environmental drivers behind the spatial distribution of marine ecosystems.

The analysis presented here is part of iAtlantic's basin-scale habitat mapping exercise, and the automated cluster analysis is a major deliverable under this effort. This work has been submitted for publication to *Frontiers in Marine Science*: Schumacher, M. et al. (submitted) The Atlantic Ocean Landscape: A basin-wide cluster analysis of the Atlantic near seafloor environment.

Figure 1 (right): Atlantic Seabed Area map showing the nine seabed areas (SBAs) that portray the Atlantic seafloor. Grey areas are cells with a classification probability of less than 98%



Atlantic Seabed Areas

- SBA I: Oxic, POC flux influenced, mostly flat with regionally thick sedimented coverage current influenced regions with low seasonal change
- SBA II: MAR spreading centre including abyssal ridges, trenches, seamounts and continental slopes as well as the Gulf of Mexico.
- SBA III: Deep, cold, fresh and oxygen depleted abyssal plain with increased bottom current velocity
- SBA IV: Shallow, warm, nutrient-rich and saline deeper shelf/upper slope zones with thick sediment cover, strong currents and strong local and seasonal changes
- SBA V: Small and regional, cold and fresh deep water influenced areas in North and South Atlantic at medium depth, with locally increased currents and current seasonal change
- SBA VI: Central deep Atlantic cool, nutrient-depleted area with very weak currents, covering some abyssal elevations and sinks
- SBA VII: Small and regional, deep, flat, sedimented oxic region with strong currents and high seasonal current change
- SBA VIII: Wider region around MAR covering new seafloor, faults and fracture zones, with extremely low sediment cover, no currents, very low oxygen and temperature
- SBA IX: Nutrient-rich, fresh, warm water continental shelf regions with thick sediment cover and strong seasonal fluctuations

Ref. Ellipsoid: WGS 84;

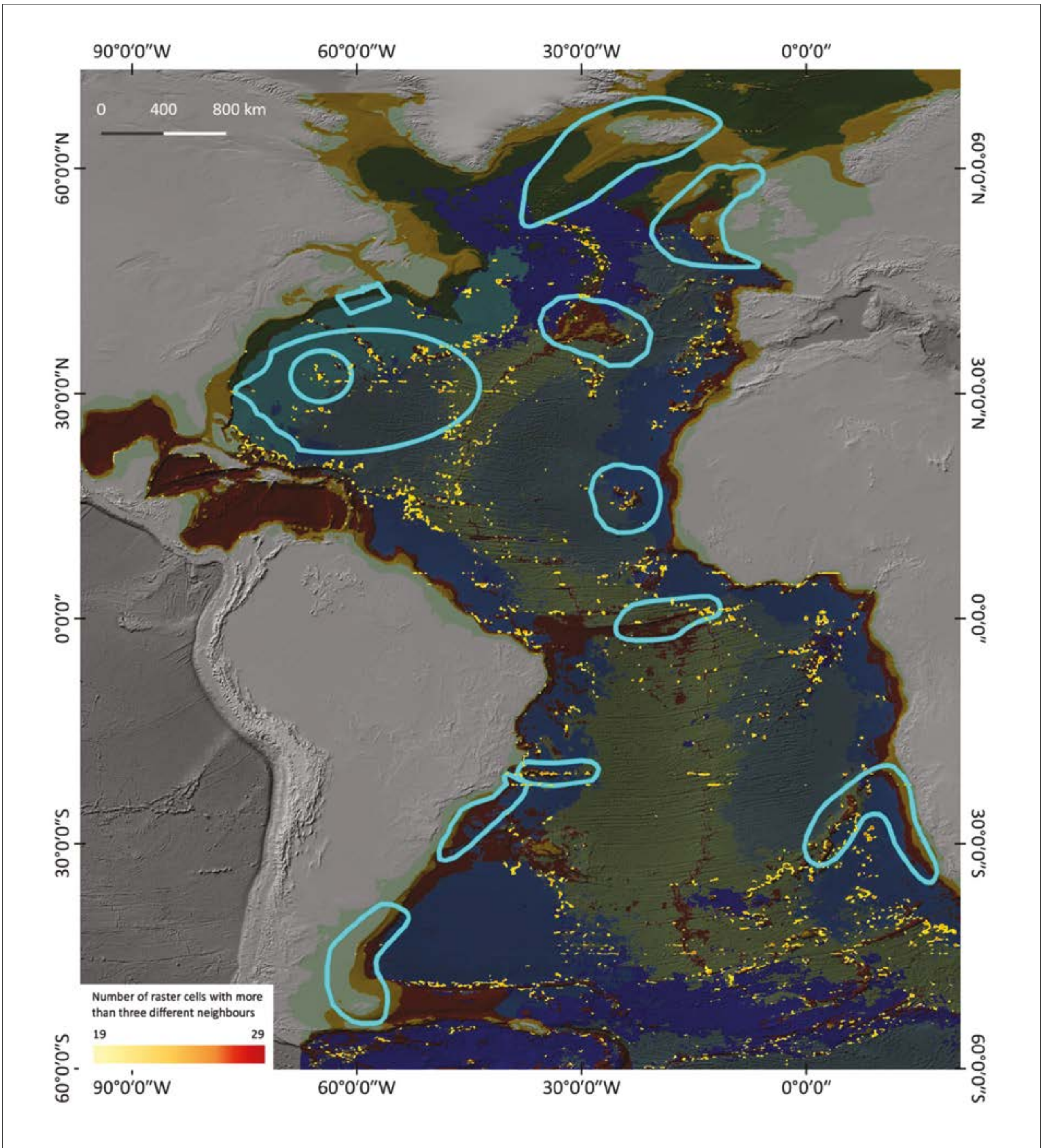


Figure 2: Results of a landscape diversity analysis. Areas where many different landscape patches meet are highlighted yellow-red. iAtlantic study areas are outlined in light blue.

On the topic of mid-ocean ridges...

...this paper is just out, part of a *Frontiers in Marine Science* special issue on 'Understanding Ocean Ridges, a New Frontier for Science and Development: Priede et al. (2022) Drivers of Biomass and Biodiversity of Non-chemosynthetic Benthic Fauna of the Mid-Atlantic Ridge in the North Atlantic. *Frontiers in Marine Science*. [DOI: 10.3389/fmars.2022.866654]

iAtlantic at GeoHab2022

The annual GeoHab conference, now in its 21st year, brings together over 150 biologists, geologists, environmental scientists, spatial analysts, technologists, geophysicists and environmental advisors from around the world, and provides a unique multidisciplinary forum for the exchange of knowledge and ideas that underpin sustainable ocean management.

This year's event took place at Venice International University, Venice, on 16-20 May 2022. The programme featured oral and poster presentations along seven themes: i) shelf and deep-sea habitats; ii) coastal and shallow water habitats; iii) submerged landscapes and cultural heritage; iv) the Anthropocene and the effect of human footprint on marine habitats; v) new approaches from coast to deep water habitat mapping; vi) habitat mapping and climate change, and vii) habitat mapping for maritime spatial planning (MSP) within an ecosystem-based approach.

The GeoHab conferences are a key outlet for results achieved under iAtlantic's work package on 'Mapping Atlantic Ecosystems' (WP2), and this work was well represented in Venice with a range of presentations from project researchers and iAtlantic Fellows:

Mapping of Vulnerable Marine Ecosystem (VME) indicator taxa off Cabo Verde (Eastern Equatorial Atlantic Ocean)
Beatriz Vinha and colleagues (oral presentation)

Mapping Local and Species Contributions to Beta Diversity in the Porcupine Bank Canyon
Felix Butschek and colleagues (poster presentation)

Mapping and morphologically characterizing cold-water coral mounds across the Atlantic Ocean
Laurence De Clippele and colleagues (oral presentation)

3D Photogrammetric classification of cold-water coral reefs with machine learning - preliminary results from Piddington Mound, NE Atlantic
Larissa M.C de Oliveira and colleagues (oral presentation)

The Atlantic Marine Landscape: A basin-wide cluster analysis of near-seafloor physico-chemical conditions
Mia Schumacher and colleagues (oral presentation) - see more about this in the article on p22-24 of this newsletter!

iAtlantic Fellows Beatriz Vinha and Larissa M.C. de Oliveira were proud and grateful recipients of travel grants from the Ron McDowell Student Support Award, awarded each year by the conference organising committee to enable selected students to attend and present their work at the meeting.

GEOHAB 2022
Marine Geological & Biological Mapping

Below: The iAtlantic team at GeoHab2022 in Venice (left to right): Prof Andy Wheeler (UCC), Felix Butschek (UCC), Beatriz Vinha (U.Saento/IEO), Larissa Macedo Cruz de Oliveira (UCC), Cat Wardell (NOC), Mia Schumacher (GEOMAR), Dr Laurence De Clippele (UEDIN) and Ger Summers (UCC). Image courtesy Cat Wardell.

Coupling population genomics and larval dispersal modelling: a promising way of monitoring species connectivity in the deep sea

By Portanier E., LePort A.-S., Nicolle A., Morrison C., Cunha, M., Cordes E., Young C.M., Van Dover C.L., Biastoch, A., Thiébaut E. & Jollivet D.

Over the past two decades, population genetics and molecular barcoding studies of deep-sea species have accumulated evidence suggesting the possibility of a shared history between active margin fauna on both sides of the North Atlantic Ocean (Andersen et al. 2004, Olu-LeRoy et al. 2007, Hilario et al. 2011, Teixeira et al. 2013, LaBella et al. 2017). To date, these analyses have however not determined with accuracy the relative contribution of both the demographic history of populations and the current dynamics of exchanges across the Atlantic Ocean via the dispersal of their propagules to the genetic structure of species living there. As such, the coupling of studies of present-day population connectivity through genome-wide genetic approaches with 'large-scale' modeling of larval dispersal at different depths based on our knowledge of the biology and ecology of the same species offers particularly promising prospects (Breusing et al. 2016; 2021). In this context, the Atlantic Ocean monitoring programme, through the H2020 iAtlantic project, made such perspective possible thanks to the use of the VIKING 10/20 and INALT 10/20 ocean circulation models developed at GEOMAR (Kiel, Germany) and the production of individual genomic libraries targeting cold seep mussels from the American, African and European active margins at the SBR (Roscoff, France). This novel work was for the first time made possible by collecting nearly all currently available mussel samples between European and American laboratories.

Until now, most of the specimens have been barcoded with the mitochondrial marker *Cox1* to better identify species presence and establish a first level of spatial structuring of the interconnected populations of the two main species complexes of deep-sea mussels exploiting hydrocarbon/methane seeps, namely: *Bathymodiolus heckerae/*

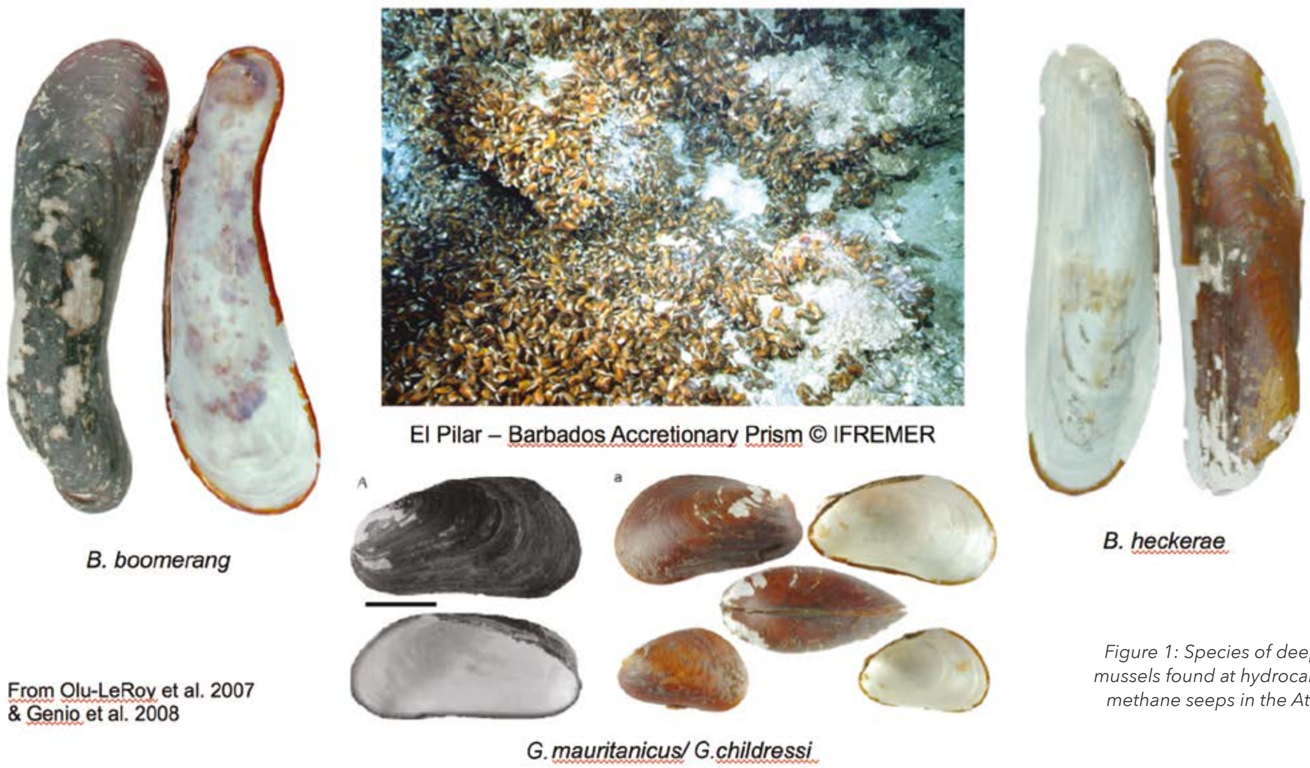


Figure 1: Species of deep-sea mussels found at hydrocarbon/methane seeps in the Atlantic

boomerang and *Gigantidas childressi/mauritanicus* (Fig. 1, *cf* Olu-LeRoy et al. 2007; Genio et al. 2008). These mussels harbour methanotrophic and sulpho-oxidising symbionts in their gills to feed on the organic carbon derived from the energy of the methane/sulphide oxidation.

The observed genetic structures are presented here as two distinct haplotype networks, and the associated maps of their geographic distribution (Fig. 2) provide a first basis for the possible role of the global North Atlantic circulation in the recent dispersal of these species. In particular, they show the probable arrival of propagules on the African coasts from seeps of the Barbados accretion prism in the species *B. boomerang*, and the existence of an older connection between *G. childressi* and *G. mauritanicus* at the level of the northeastern overturning loop of the AMOC between the New England Shelf Break and the northwestern coast of Europe. These first results are in good agreement with simulations of larval dispersal carried out in parallel on 20 localities distributed on both sides of the Atlantic based on a pelagic larval duration (PLD) of one year with a progressive ascent of larvae to the surface until they reach the thermocline (Fig. 2B). These dispersal simulations reinforce the hypothesis of present-day exchanges at the latitude of the Atlantic equatorial belt. Conversely, the genetic data unexpectedly refute the existence of exchanges between the Barbados accretionary prism and the Gulf of Mexico, despite the incoming flow of larvae predicted by the physical models of water-mass circulation. In this particular case, the lack of connectivity between these populations could be explained by the high temperature/salinity of the surface waters: a hypothesis that still remains to be tested.

Quantification of gene flow between populations, their directionality and temporality is currently underway through the analysis of multigenic SNPs datasets obtained from the sampling and filtering of the massive amount of genomic reads obtained for hundreds of individuals of these species. These data will be valuable in the conservation biology of species from highly fragmented deep-sea environments and their putative evolution in the face of global warming and the associated modification of the oceanic circulation. In particular by combining potential and realised dispersal, one should be able to specify the most probable conditions of larval migration both in terms of positioning and effective duration in the water column.

References

Andersen et al. (2004) Escarpia southwardae, a new species of vestimentiferan tubeworm (Annelida, Siboglinidae) from West-African cold seeps. Journal of Canadian Zoology, 82, 980-999.

Breusing et al. (2016) Biophysical and population genetic models predict presence of "phantom" stepping stones connecting Mid-Atlantic Ridge vent ecosystems. Current Biology, 26(17), 2257-2267.

Breusing et al. (2021) Differential patterns of connectivity in Western Pacific hydrothermal vent metapopulations: A comparison of biophysical and genetic models. Evolutionary Applications, DOI: 10.1111/eva.13326, 1-14.

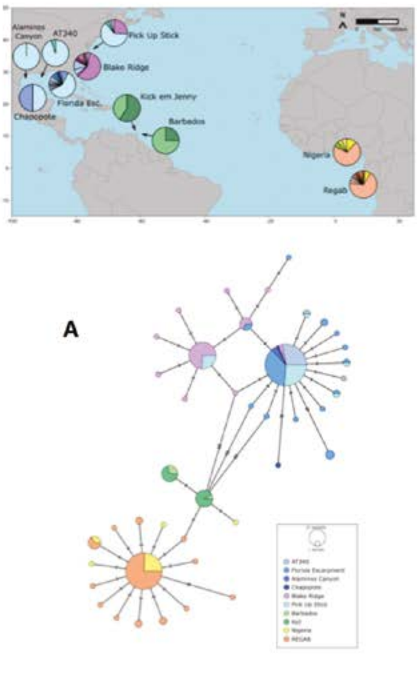
Génio et al. (2008) New record of "Bathymodiolus" mauritanicus Cosel 2002 from the Gulf of Cadiz (NE Atlantic) mud volcanoes. Journal of Shellfish Research, 27(1), 53-61.

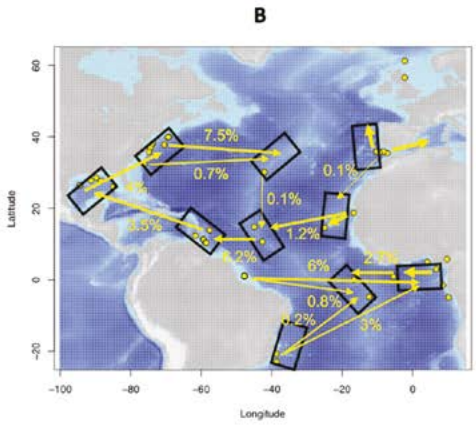
Hilario et al. (2011) New perspectives on the ecology and evolution of siboglinid tubeworms. PloS One, 6(2), e16309.

LaBella et al. (2017) Gene flow between Atlantic and Pacific Ocean basins in three lineages of deep-sea clams (Bivalvia: Vesicomyidae: Pliocardiinae) and subsequent limited gene flow within the Atlantic. Deep Sea Research Part II: Topical Studies in Oceanography, 137, 307-317.

Olu-LeRoy et al. (2007) Amphi-Atlantic cold seep *Bathymodiolus* complexes of species across the Equatorial belt. Deep-Sea Research I, 54, 1890-1911.

Teixeira et al. (2013) High connectivity across the fragmented chemosynthetic ecosystems of the deep Atlantic Equatorial Belt: efficient dispersal mechanisms or questionable endemism? Molecular Ecology, 22(18), 4663-4680.





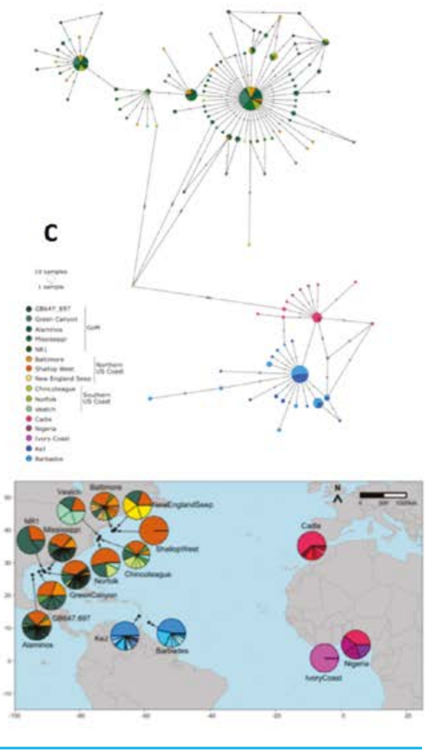
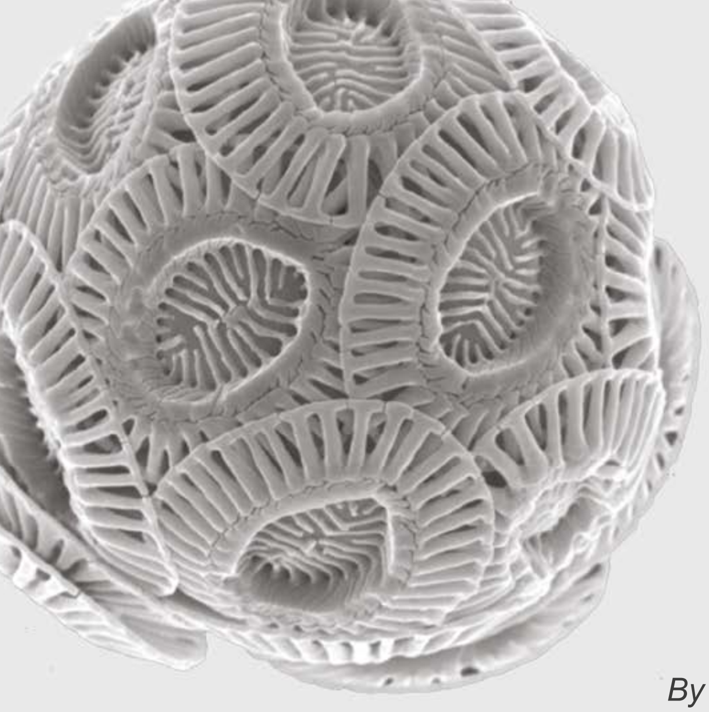


Figure 2: Population connectivity of seep mussels within and between continental margins of the Atlantic. A) Geographic distribution of B. boomerang *and* B. heckerae *haplotypes together with their genetic relationships in the associated network, B) Larval flows inferred by the oceanographic model VIKING 20/10 from 20 seep localities to 10 Atlantic regions with a one-year PLD, and C) Geographic distribution of* B. childressi *and* B. mauritanicus *haplotypes together with their genetic relationships in the associated network.*



Emiliania huxleyi *coccolithophores - their ancient DNA was detected in cores used in this study. Image courtesy A.R. Taylor (U. North Carolina Wilmington Microscopy Facility), CC BY 2.5 via Wikimedia Commons*

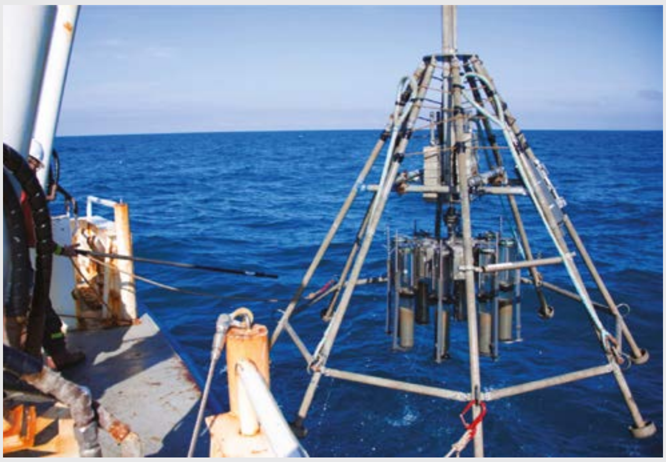
Is there detectable ancient DNA present in archived marine sediment cores?

By Caitlin Selway[1], Linda Armbrecht[1,2] & David Thornalley[3]

1. Australian Centre for Ancient DNA, University of Adelaide, Adelaide, SA, Australia,
2. Institute for Marine and Antarctic Studies (IMAS), University of Tasmania, Hobart, TAS, Australia,
3. Department of Geography, University College London, London, UK

An objective of iAtlantic is to explore novel methods of examining ecosystems in both the present and past. The seafloor is a natural archive of marine organisms that have lived in the past. When marine organisms die, they sink to the bottom of the ocean, and over thousands of years, they form layers as part of the sedimentary record. Traditionally, microscope counts and geochemical analyses of fossilised eukaryotes, such as diatoms, foraminifera, dinoflagellate cysts, radiolaria, and coccolithophores, have been used to reconstruct past oceanographic and ecological changes.

However, such microfossil-based reconstructions are limited, as only the more robust and fossilised species are preserved in seafloor sediments, meaning that the vast number of soft-bodied organisms that have also thrived in the past ocean are not accounted for. The study of sedimentary ancient DNA (sedaDNA) has the potential to fill this gap and achieve a more complete picture of past marine ecosystems across the whole food web, which will be useful to help improve our understanding of possible future ecosystem responses to climate and ocean changes.



The study of marine sedaDNA involves the analysis of DNA from organisms that have inhabited the ocean in the past, and that have since sunk to the seafloor and become preserved in the sediment record. Due to the extensive risk of contamination with modern DNA, it is recommended that samples for sedaDNA research are purpose-collected, but this limits the availability of samples for sedaDNA analysis to a relatively small pool of available sediment cores recently collected following extensive decontamination procedures. In contrast, thousands of cores from field campaigns carried out over the last few decades are currently stored as “archive material” at various core repositories around the globe. Being able to utilise this archive material would unlock an immense resource to the field of marine sedaDNA research. As part of iAtlantic, we analysed North Atlantic sediment cores that were archived in core repositories to determine if this type of long-term stored material was suitable for sedaDNA analyses.

A common approach for analysing environmental DNA for modern ecological studies is to undertake metabarcoding – a technique where a taxonomically informative gene region of a specific size is amplified and damage patterns are usually repaired during the experimental process. However, this approach is less suitable for detecting and analysing ancient DNA. This is because, to verify that the genetic signal obtained is truly ancient, both DNA fragment-size variability and DNA damage patterns are required. Such authentications cannot be achieved by metabarcoding because the original size-variability and damage patterns are not preserved.

Instead, we employed shotgun sequencing, where the DNA from all organisms (i.e., ‘total’ DNA) in a sample was analysed. These approaches are computationally intense and costly. However, these approaches are the only means to obtain the

Left: Collecting sediment cores from the North Atlantic – here, from south of Iceland. Image courtesy Ian Hall, Cardiff small sedaDNA fragments typical for ancient DNA, including their characteristic DNA damage patterns. This study was the first application of a metagenomic shotgun sequencing approach to acquire sedaDNA from archive marine sediment samples from the deep seafloor.

We analysed two samples (one younger and one older – up to 20,000 years old) at five sites. We were able to extract sedaDNA from all samples and observed DNA damage patterns and fragment lengths for the eukaryotic material that was characteristic of ancient DNA. We detected abundant sequences of the coccolithophore *Emiliania huxleyi*, which is widely distributed in the modern ocean. The DNA of *Bathycoccus prasinos*, a picoplankton species, was consistently observed across all samples. We also detected both fossilising and non-fossilising phyto- and zooplankton species at low abundance, including foraminifera, diatoms, and the copepod *Calanus finmarchicus*. The DNA of Atlantic cod, *Gadus morhua*, was also present in most samples.

However, we also detected strong evidence for contamination, mainly from Ascomycota (fungi), attributed to the presence of contaminants during non-ideal sampling and sample storage conditions of the investigated samples. Therefore, we stress the importance of ensuring steps are taken to mitigate contamination from sample collection and storage.

Future studies could employ a number of suggestions for methodological improvements, and there is a need for further investigation into environmental and sedimentary processes that may bias sedaDNA preservation in seafloor sediments. With continued refinement in the future, marine sedaDNA analyses offer the potential to unlock more complete reconstruction of marine ecosystems over thousands of years prior to modern observations, leading to greatly expanded knowledge of ecosystem behaviour.

Read the full article:

Selway, C.A., Armbrecht, L., & Thornalley, D. (2022) An Outlook for the Acquisition of Marine Sedimentary Ancient DNA (sedaDNA) from North Atlantic Ocean Archive Material. Paleoceanography and Paleoclimatology, 37, e2021PA004372. DOI: 10.1029/2021PA004372

There are thousands of available marine sediment cores, stored in repositories such as this one at the Woods Hole Oceanographic Institution. Image courtesy WHOI Seafloor Samples Laboratory.

A summer full of biogeochemical observations

By Kristin Burmeister, SAMS

At the Scottish Association of Marine Science (SAMS) on the west coast of Scotland, preparations for a summer full of biogeochemical ocean observations are in full swing. Not only are we organising an international workshop about biogeochemical ocean observations in June, but also packing up for our research cruise in the subpolar North Atlantic in July to recover moored oxygen sensors deployed by iAtlantic.

Biogeochemical measurements in ocean observing systems allow for assessment and sustainable management of oceanic ecosystems, yet they are underrepresented and underutilised. Myself and colleagues – an international team of 13 researchers and experts from seven different countries – are convening an observational training event to increase utilisation of biogeochemical datasets. The resulting workshop "*Best practices for biogeochemical ocean observation: instrumentation, operation, quality control*" takew place at SAMS on 15-17 June 2022, funded by the Partnership for Observation of the Global Ocean (POGO). Participants will learn how to calibrate and quality control data from biogeochemical sensors obrtained by Argo floats, moored, shipboard or glider observations. The training also features a mini conference where participants can present their own research, with the challenge to do so in just five minutes.

Preparations are in full swing. The training is offered as a hybrid event – trainers and participants will attend both virtually and in person. This new mode of event organisation is challenging but enables an amazing amount of flexibility. We have participants from 21 countries from Europe, America, Africa and Asia. Our collaboration with two other independent POGO observational training initiatives allows

Figure 1: Deployment of a mooring from RRS Discovery at the OSNAP array in the North Atlantic during expedition DY120, October 2020 (image courtesy Sam Jones, SAMS).

us to reach even a broader audience through the sharing of training resources. We are looking forward to the training in June and can't wait to meet the participants in Oban and online.

Skills learned at the workshop can be put into action just one month later, during the research cruise on RSS *James Cook* in the North Atlantic. The cruise forms part of the UK Overturning in the Subpolar North Atlantic Programme (UK-OSNAP) and Ellett Array projects, and aims to better understand ocean circulation and fluxes through continuous observations of the North Atlantic Subpolar Gyre (see Fig. 2). The OSNAP array was installed in 2014 to monitor the Atlantic Meridional Overturning Circulation (AMOC), a large system of ocean currents that spans the entire Atlantic. Its upper part transports warm water towards the north, whilst its lower part, deep below the ocean surface, transports cold water southwards. The AMOC plays an important role in mixing the world's ocean and distributing heat across the planet, thus influencing the climate. iAtlantic is contributing oxygen sensors to the OSNAP mooring array which were installed in 2020 from RSS *Discovery* (Fig. 1). Together with pH measurements (from the ATLAS project), this will give new insights to AMOC impacts on carbon fluxes.

During the cruise we will deploy six BGC-Argo floats, turn around six moorings along the Ellet line and OSNAP array in the Rockall Trough and the Iceland Basin, and install a new drift-free bottom pressure recorder in the Rockall Trough. The bottom pressure recorder will stay in the water for 10 years and its data will be harvested remotely via an acoustic modem without the need to recover the instrument. This is unprecedented for AMOC observations. A similar sensor will be deployed by German colleagues at the western border of the Atlantic basin. The new bottom pressure recorders have the potential to monitor long-term changes in the AMOC with minimal observational effort. Because the sensors are drift free, the smallest changes like a continuous trend will be identifiable. This was not possible before because previous bottom pressure recorders were dominated by a strong sensor drift which only allowed us to study changes on timescales shorter than the deployment period. This opens a whole new world of sustained basin-wide ocean transport observations.

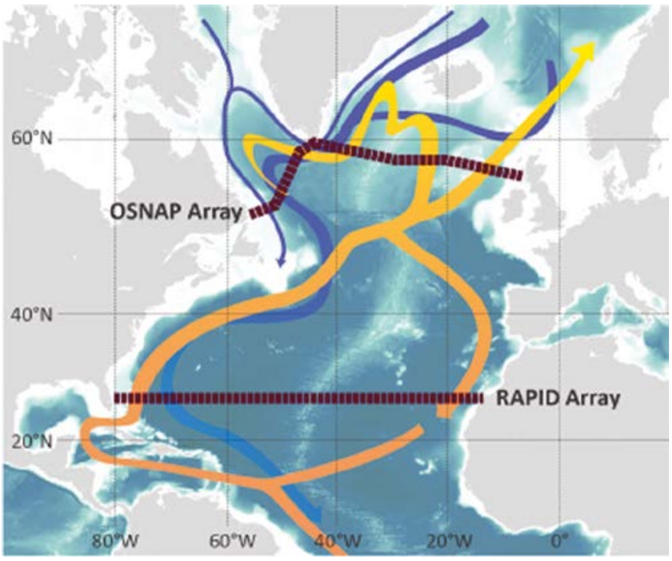
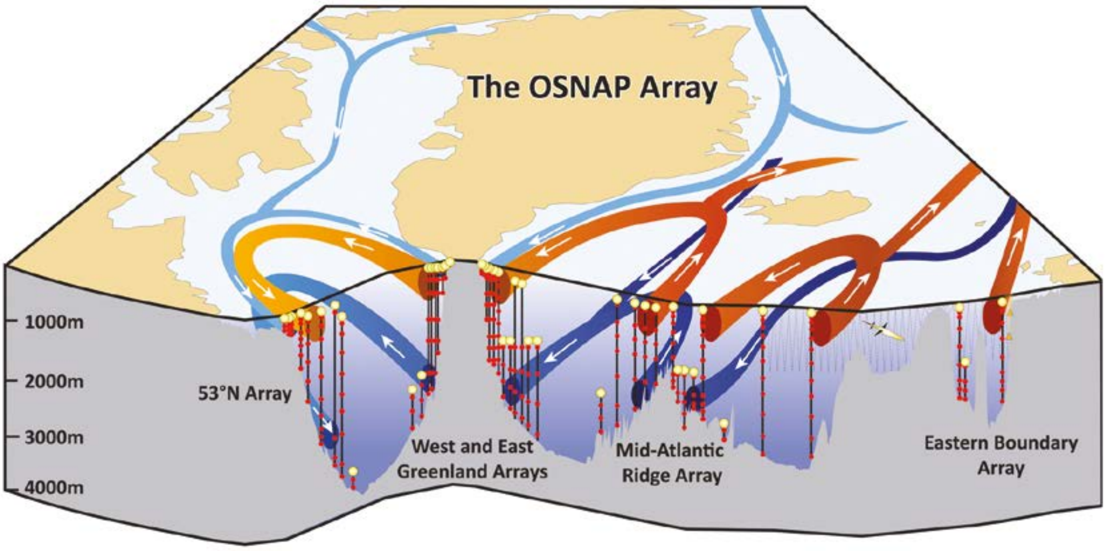


Figure 2: A schematic of the OSNAP mooring array (below), the location of which is also shown on the map (left). Warm currents in the upper one kilometer which flow north from the Gulf Stream and North Atlantic Current are shown in red and orange. The warm water cools as it flows round the subpolar gyre and in the Nordic and Labrador Seas east and west of Greenland. The cold waters in blue return southward at depths of one to four kilometers. This is the overturning circulation. To continuously monitor the strength and structure of all these currents, an array of moorings is continuously deployed between Newfoundland and West Greenland and East Greenland and Scotland. A mooring is a wire (black vertical lines) from the seabed to just below the surface and is held taught and vertical by syntactic foam and glass buoyancy (yellow dots). Instruments such as current meters, and temperature and salinity sensors are fixed to the wires (red dots). Every two years, over a period of three summer months, all the moorings are recovered during research expeditions. The data from the instruments can be downloaded for analysis New moorings and instruments are deployed for another two years. In the Eastern Boundary Array autonomous gliders (yellow vehicle with black wings), 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.



iAtlantic

Voyage to the Ridge

Okeanos Explorer undertakes a massive mapping mission in the deep North Atlantic this summer

Research vessel Okeanos Explorer*. Image courtesy NOAA Office of Ocean Exploration and Research*

For three months from May through to mid-August 2022, the NOAA research vessel *Okeanos Explorer* will carry out an ambitious programme of deep-sea exploration in the North Atlantic Ocean. The hotly-anticipated 'Voyage to the Ridge' expedition forms part of NOAA Ocean Exploration's contribution to the Atlantic Seafloor Partnership for Integrated Research and Exploration (ASPIRE) campaign in support of the Galway Statement on Atlantic Ocean Cooperation, with Atlantic expeditions focusing on the south-east United States margin, the Caribbean and the Mid-Atlantic Ridge (Fig. 1).

iAtlantic will benefit hugely from the campaign this summer, which involves extensive seafloor mapping and ROV dives across the Mid-Atlantic Ridge, Azores Plateau, and Charlie-Gibbs Fracture Zone. Geologically, this includes a divergent plate boundary, volcanism and hydrothermal vents; biologically, these areas are anticipated to host a diverse variety of marine life including vent fauna, species living on hard substrate and animals travelling along the migration corridors that connect the eastern and western margins of the Atlantic basin. The data collected will help fill important knowledge gaps about deep-sea ecosystems and habitats in these relatively unexplored areas of the Atlantic.

iAtlantic scientists have been closely involved in helping plan dive locations and sampling strategies for this expedition, but participation is open to everyone thanks to the telepresence capability on *Okeanos Explorer*. This allows shore-based scientists to directly join the exploration effort via a dedicated high-quality ROV camera livestream platform for the science community and by conference call direct to the onboard science team to help guide the dives, direct sampling activity and to assist with dive annotation and species identification. The public can also join in, with access to the live ROV footage openly available via the NOAA Ocean Exploration website.

Scientists and managers interested in actively participating in the expedition can find out more at the Okeanos Explorer: Get Involved webpage. If you are interested in providing input into expedition planning or participating as a scientist or student, contact the expeditions science advisor, Scott France, at france@louisiana.edu.

Voyage to the Ridge: Key dates and details

11 May - 7 June 2022: Voyage to the Ridge 1
(EX-22-04) MAPPING: Starting in Newport, Rhode Island, and ending in St. Johns, Newfoundland (Canada)

16 June - 13 July 2022: Voyage to the Ridge 2
(EX-22-05) ROV & MAPPING: Starting in St. Johns, Newfoundland (Canada), and ending in Horta, Faial, Azores (Portugal)

22 July - 18 August 2022: Voyage to the Ridge 3
(EX-22-06) ROV & MAPPING: Starting in Horta, Faial, Azores (Portugal), and ending in St. Thomas, US Virgin Islands

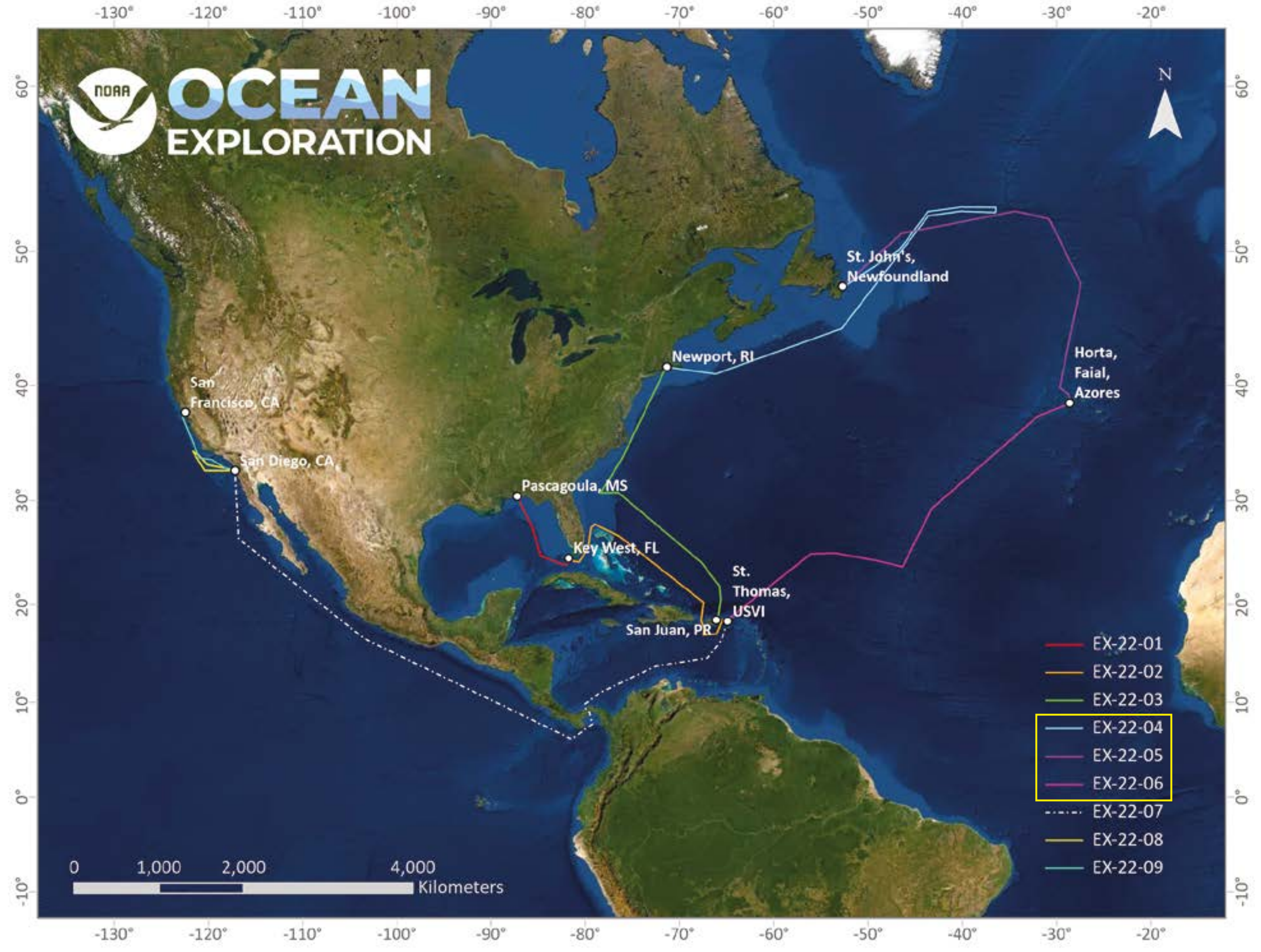


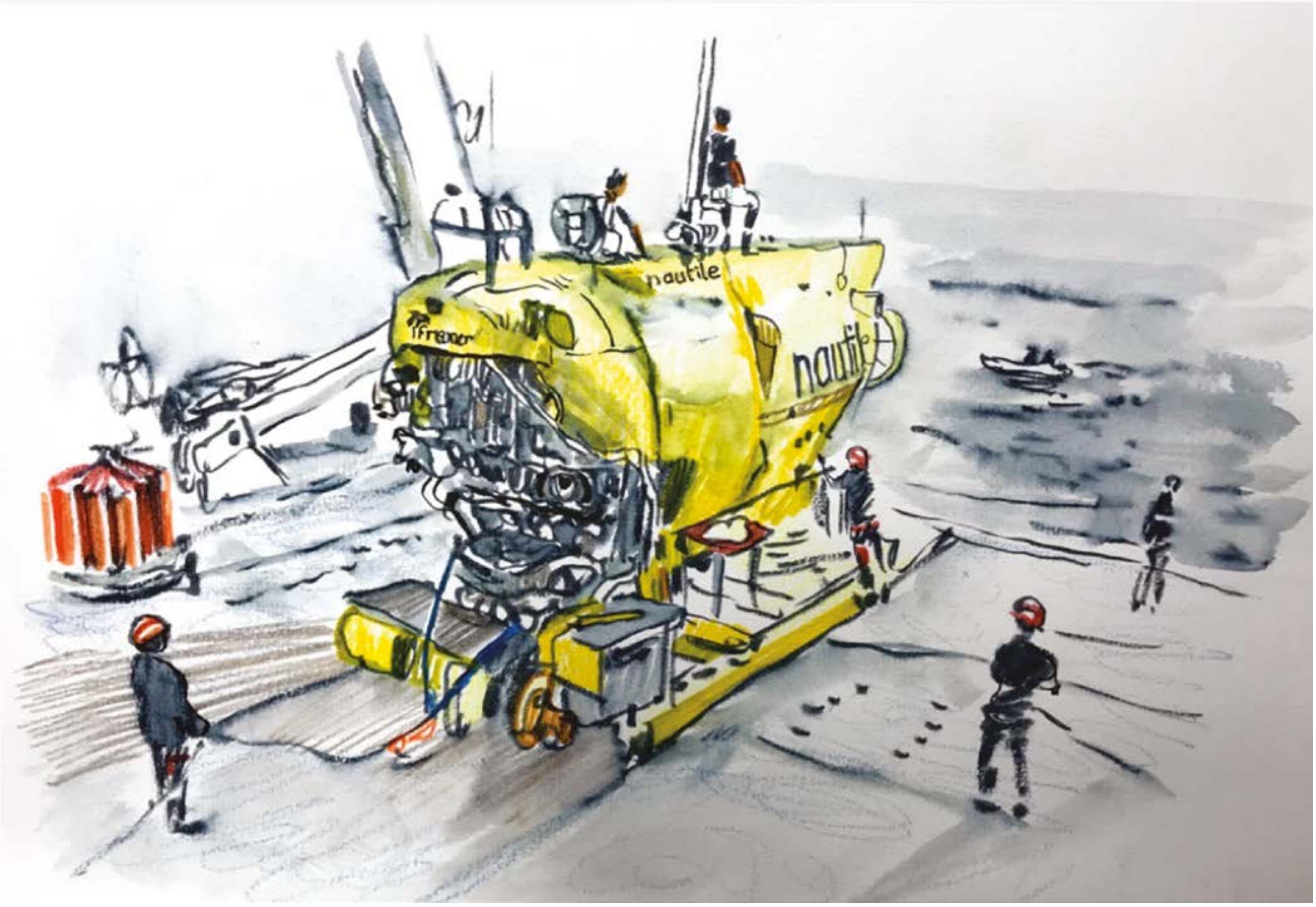
Figure 1: Map showing planned expedition route for the Okeanos Explorer *in 2022. Legs most relevant to iAtlanitc are EX22-04, EX22-05 and EX-2206 (ringed in yellow on the key). Map courtesy NOAA Ocean Exploration.*

Renewed hope for the Charlie-Gibbs Fracture Zone

The Charlie-Gibbs Fracture Zone (CGFZ) is a unique and prominent geological feature of the North Atlantic, running for more than 2,000 km east-west across the section of the Atlantic between Iceland and the Azores and offsetting the zipper-like Mid-Atlantic Ridge by some 350 km. Its complex geological structure comprises two parallel transform faults that form deep and seismically active rift valleys, and – together with nearby seamounts – creates a rugged seafloor topography in water depths ranging 700-4,500 m. The surrounding ocean is a zone of strong currents and intense mixing, with nutrient-poor warm waters from the south of the fracture zone mixing with cooler, nutrient-rich water from the north, creating an amazingly rich environment for marine life. The CGFZ provides the only route for deep-water and faunal exchange between the north-east and north-west Atlantic, though deep-sea fauna on the eastern and western flanks of the Mid-Atlantic Ridge remain fairly isolated from each other. The CGFZ's unique features are recognised and protected, in part, by a marine protected area under the purview of OSPAR, and it has been described as meeting the criteria for an ecologically or biologically significant marine area under the Convention of Biological Diversity*. Further recognition of the CGFZ's unique and important features comes this summer, with a renewal of its status as a Mission Blue Hope Spot. Professor David Johnson, the new Hope Spot Champion for CGFZ, is looking to build on his involvement with CGFZ that he gained when he was Executive Secretary to the OSPAR Commission: "NOAA's *Voyage to the Ridge* expedition provides an amazing opportunity to better appreciate the biodiversity, to build on and update the scientific information underpinning management measures, and to anticipate the impact of potential future pressures in this important region of the North Atlantic".

** to be considered by CBD COP15.*

MoMARSAT 2022: RV *Pourquoi pas?* makes its annual visit to the EMSO-Azores observatory



Launching the first dive of the submersible Nautile at 1700 m depth on the Lucky Strike vent field (image © D. Roudeau/Ifremer/Momarsat2022)

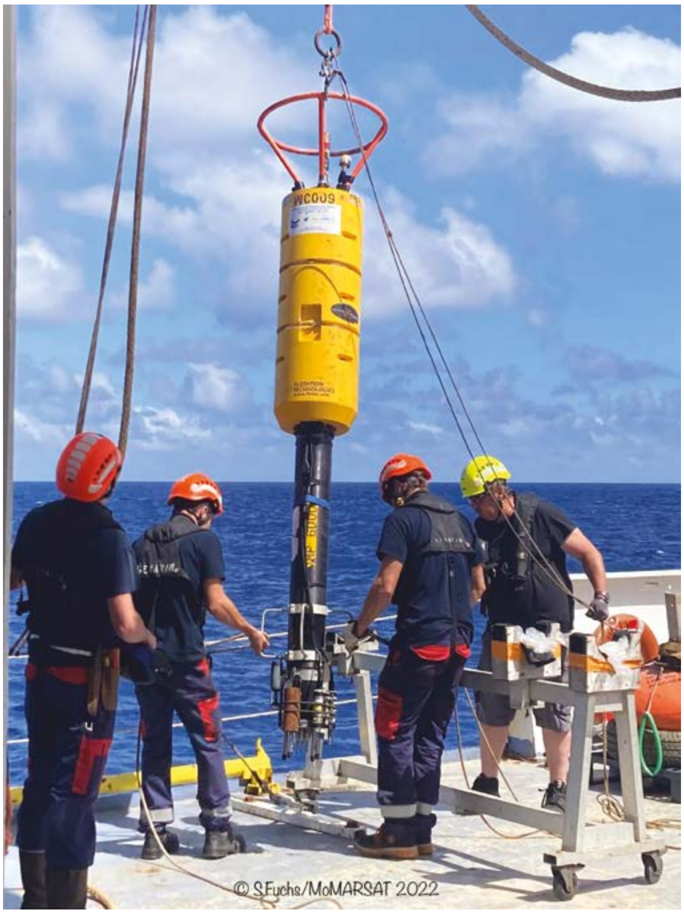
The MoMARSAT 2022 cruise is under way! Taking place on 6-27 June 2022 and journeying to the northern Mid-Atlantic Ridge, the expedition will carry out the yearly maintenance of the EMSO-Azores observatory. A team of 30 scientists from Ifremer, CNRS (IPGP, GET, MIO, LPO), University of Western Brittany (UBO) and University of the Azores are on board the French research vessel *Pourquoi pas?* heading in the direction of the Lucky Strike vent field off the Azores. The French manned submersible *Nautile* will be used to oversee all operations on the seafloor. The multidisciplinary scientific team is composed of 13 researchers, PhD and Master students as well as 15 engineers and technicians – collectively they will ensure the maintenance and continued smooth running of the observatory, its autonomous sensors and associated sampling programme. This year, the team invited artist Daniel Roudeau along who will, throughout the cruise, capture the ship's activities through a number of sketches and illustrations.

EMSO-Azores is a non-cabled multidisciplinary observatory dedicated to the long-term integrated study of mid-ocean ridge processes, from the sub-seafloor to the water column, from geophysics to biological responses. The observatory is composed of two SEAMON (Sea Monitoring Nodes) stations and a surface buoy Borel. The first station – SEAMON west – is dedicated to geophysical studies. It is located in a fossil lava lake, away from hydrothermal vents and connects a bottom seismometer (OBS), a permanent pressure gauge and a European Generic module (EGIM) equipped with CTD, optode, hydrophone, turbidity meter, tsunami pressure sensor and ADCP. This EGIM allows long-term monitoring of background seawater dynamics. The second station – SEAMON East – is located at the base of the active Tour Eiffel hydrothermal edifice. It provides power and communication to a high-resolution video camera with two LED projectors (TEMPO), an instrumented microbial coloniser (CISICS), turbidity meter, optode and a prototype fluid sampler DEAFS that sequentially collects end-member fluids from a bell deployed directly on a black smoker. A surface buoy – BOREL – ensures data transfer between the two bottom stations and the Ifremer headquarters in Brest, and is equipped with a geodesic GPS and a meteorological station. During the year, a satellite link allows data transmission to land every 6 hours. During this cruise, the two stations and the surface buoy will be recovered and redeployed after reconditioning on board. Scientists are eager to see their data and learn all about events that occurred at the site over the year!

Repeated in situ collection of fauna, fluids and rocks, as well as measurement of a number of parameters will complement the temporal monitoring of the vent sites while extending the spatial extent of our studies. Some experimental studies will also be carry out to evaluate carbon transfer between the different faunal species associated with vent mussel communities.

To complement this multidisciplinary and interdisciplinary approach, a team of physical oceanographers will deploy Microryo, a new mooring dedicated to the study of local microstructure turbulences and perform, in between dives, several vertical profiles using a Vertical Microstructure Profilers (VMP) and CTD.

We also have at heart to share our experience at sea and raise awareness. A Facebook page for the general public will be active during the entire cruise and the drawings from our sketcher Damien Roudeau will be posted daily on Instagram (@Momarsat).



Clockwise from top right: deployment of the BOREL buoy; preparing the vertical microstructure profiler for action (both images courtesy S.Fuchs/ MoMARSAT 2022); artist's impression of RV Pourquoi pas? *ahead of the expedition departure (image courtesy D. Roudeau).*

Collaborative workshop on deep-sea research offshore Cabo Verde

Irene Perez-Rodríguez[1], Julie C. Schindlbeck-Belo[2], Colin Devey[2], Thor H. Hansteen[2], Veerle Huvenne[3,4], Jacek Raddatz[5], Mia Schumacher[2], Beatriz Vinha[6] & Covadonga Orejas[2,4,7]

1. Centro Oceanográfico de Vigo, Instituto Español de Oceanografía, IEO-CSIC, Vigo, Spain

2. GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany

3. National Oceanography Centre, Southampton, United Kingdom

4. Hanse-Wissenschaftskolleg Institute for Advanced Study, Germany

5. Institute of Geosciences, Sedimentology, Goethe University, Germany

6. Department of Biological and Environmental Sciences and Technologies, Salento University, Lecce, Italy

7. Centro Oceanográfico de Gijón, Instituto Español de Oceanografía, IEO-CSIC, Gijón, Spain

The Collaborative Workshop on Deep-Sea Research Offshore Cabo Verde took place at GEOMAR, Helmholtz Centre for Ocean Research, Kiel, Germany, on 11 February 2022. This initiative was convened to facilitate cooperation between researchers working on different aspects of the marine life and geological setting around Cabo Verde archipelago. This area is very productive and diverse due to different process such as the regional upwelling, the input of Saharan dust into the ocean and the active volcanism that forms important seamounts, which are home to species-rich ecosystems.

The main objectives of the workshop were to present the available datasets and work in progress, enhance and stimulate the integration of disciplines, propose new ideas and potential studies, and plan future work accordingly.

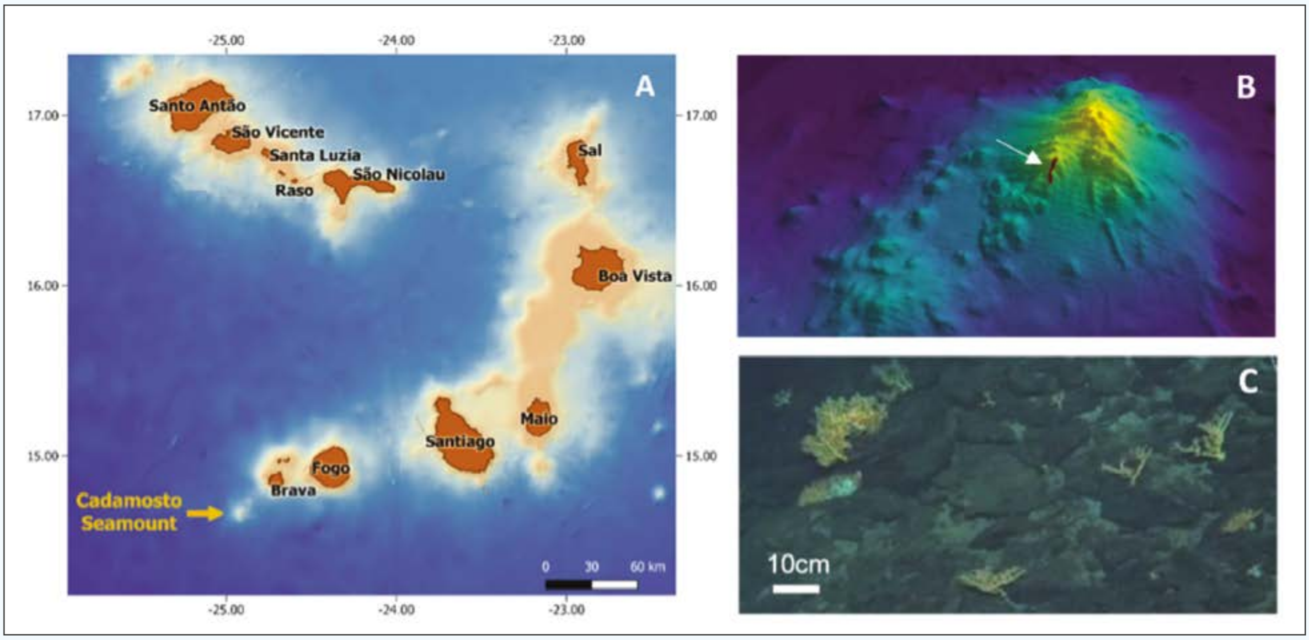
Two marine expeditions carried out in Cabo Verdean waters are the main data sources of the ongoing studies: iMirabilis2, conducted as part of iAtlantic in July-August 2021 aboard the Spanish RV *Sarmiento de Gamboa,* and M80/3 carried out December 2009 to February 2010 on the German RV *Meteor*. A crucial source of information after these scientific cruises are the underwater videos obtained thanks to remotely operated vehicles (ROVs). This imagery provides valuable information for different disciplines, for instance, some biologists study the planktonic dwellers as the ROV travels through the water column, while others focus on the benthic organisms of the sea bottom, assessing the occurrence, biodiversity and the vulnerability of the ecosystems. From the point of view of geoscience, a broad spectrum of information can be extracted, such as detecting the existence of hydrothermal activity or recording the substratum types (volcanic rocks, mud, sand, pebbles, etc.). Additionally, the processing and the combination of all these multidisciplinary data allow

Workshop participants, from left to right: Mia Schumacher (GEOMAR), Irene Perez-Rodríguez (IEO), Veerle Huvenne (NOC), Colin Devey (GEOMAR), Beatriz Vinh (U.Salento/IEO), Thor H. Hansteen (GEOMAR) and Covadonga Orejas (IEO).

Cadamosto Seamount

Much of the effort invested so far by the workshop attendees has been focused on investigating the Cadamosto Seamount. This is a 3,000 m high submarine volcano located on the south-west slope of the Island of Brava. It is one of the seismically most active structures in the archipelago, it presents hydrothermal activity, and volcanic vents were frequently recognised in the underwater video records. Furthermore, its volcanic ashes can be found in the marine sediments over several tens of kilometres. The summit is dominated by phonolitic rocks, dated to be between 20,000 - 100,000 years old. This type of rock is unusual and contrasts with the typically mafic volcanic edifices at Cabo Verde.

Large cold-water coral gardens have been documented at Cadamosto Seamount, among them, a large field of *Enallopsamia rostrata*. Some of the older specimens of this species, collected during the RV *Meteor* expedition, have been dated as c. 600 years old. At that time there were no human inhabitants in the Cabo Verde archipelago, and the Europeans were still not aware of the existence of the American continent!



A) Map of the Cabo Verde archipelago showing the location of Cadamosto Seamount; B) overview of the Cadamosto Seamount indicating an ROV transect close to the summit of the seamount. The transect (red line) covers a length of about 600 m; C) large coral garden composed of Enallopsamia rostrata *on a volcanic rock substrate.*

different types of geological and habitat maps to be created. Several areas off Cabo Verde were discussed during the workshop, among them Cadamosto Seamount is one of the more explored areas and is of high interest from a scientific point of view (see box, right).

During these two cruises, different types of samples were collected, which can now be shared among the scientists to maximise their utility. For example, sediment cores are being studied with two different aims: first, to decipher aspects of the oceanography of the past such as temperature and salinity of the ancient water masses, and secondly to use the sediments to identify dispersed volcanic ash and characterise local eruptions both from the islands and the local seamounts (see article p19-20 of this newsletter).

Among the new activities proposed at the workshop, the need for future cruises to help produce a high-resolution seamount mapping and imagery was identified, to support a comprehensive assessment and propose a potential marine protected area (MPA). This initiative would be accompanied by important outreach activities, such as presenting deep-sea habitats and submarine volcanoes to the public in innovative ways.

The high level of participation and commitment of all the partners made this workshop very productive. We hope that we all can meet in person again in the future to inform about the progress we are making, as well as to share new data and ideas to improve our knowledge of this fascinating setting.

Good reads

A selection of the latest iAtlantic publications

Distribution models of deep-sea elasmobranchs in the Azores, Mid-Atlantic Ridge, to inform spatial planning
Das et al. (2022) *Deep Sea Research Part I: Oceanographic Research Papers*, DOI: 10.1016/j.dsr.2022.103707

Spatiotemporal scales of larval dispersal and connectivity among oil and gas structures in the North Sea
Mayorga-Adame et al. (2022) *Marine Ecology Progress Series*, DOI: 10.3354/meps13970]

Long-term monitoring reveals unprecedented stability of a vent mussel assemblage on the Mid-Atlantic Ridge
Van Audenhaege et al. (2022) *Progress in Oceanography*, DOI: 10.1016/j.pocean.2022.102791

Broadscale Landscape Mapping Provides Insight into the Commonwealth of Dominica and Surrounding Islands Offshore Environment
Wardell C. and Huvenne V.A.I. (2022) *Remote Sensing*, DOI: 10.3390/rs14081820

One on Top of the Other: Exploring the Habitat Cascades Phenomenon in Iconic Biogenic Marine Habitats
Kazanidis et al. (2022) *Diversity*, DOI: 10.3390/d14040290

Integrating Multidisciplinary Observations in Vent Environments (IMOVE): Decadal Progress in Deep-Sea Observatories at Hydrothermal Vents
Matabos et al. (2022) *Frontiers in Marine Science*, DOI: 10.3389/fmars.2022.866422

Variability of deep-sea megabenthic assemblages along the western pathway of the Mediterranean outflow water
Puerta et al. (2022): *Deep-Sea Research Part I*, DOI: 10.1016/j.dsr.2022.103791

An Outlook for the Acquisition of Marine Sedimentary Ancient DNA (sedaDNA) from North Atlantic Ocean Archive Material
Selway et al. (2022): *Palaeoceanography and Paleoclimatology*, DOI: 10.1029/2021PA004372

Major environmental drivers determining life and death of cold-water corals through time. da Costa Portilho-Ramos et al. (2022): *Plos Biology*, DOI: 10.1371/journal.pbio.3001628

Scan to access PDF

Want to access the digital copy of this newsletter? Use your phone to scan the QR code on the left or visit iatlantic.eu/resources

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 818123 (iAtlantic). This output reflects only the author's view and the European Union cannot be held responsible for any use that may be made of the information contained therein.

iAtlantic
INTEGRATED ASSESSMENT OF ATLANTIC MARINE ECOSYSTEMS IN SPACE AND TIME