surface ocean solas lower atmosphere study

solas event report

Report 24 I September 2022

53rd Liège Colloquium and 3rd GO$_2$NE Open Conference on Ocean Deoxygenation

Low oxygen environments in marine and coastal waters: Drivers, consequences, solutions

16 – 20 May 2022
Liège, Belgium and Online

The 53rd International Colloquium on Ocean Dynamics – 3rd GO$_2$NE Oxygen Conference took place from 15 to 20 May 2022 in Liège, Belgium. The colloquium was organised by the Intergovernmental Oceanographic Commission of United Nations Educational, Scientific and Cultural Organisation (IOC-UNESCO) Global Ocean Oxygen Network (GO$_2$NE) and was a contribution to the Global Ocean Oxygen Decade (GOOD) programme of the United Nations (UN) Ocean Decade. It was a hybrid event involving 183 on-site and 80 online participants.

"*The science is clear for ocean, land and human society: Any further delay in concerted global action will miss a brief and rapidly closing window to secure a livable future. This report offers solutions to the world. It is over to you now!*" With these words, Prof. Dr. Hans Otto Pörtner concluded his opening speech and gave the start to a full week of discussion on Ocean Deoxygenation.

Oxygen (O_2) is considered an effective indicator of ocean health and climate change. Its level, distribution and variability from sub-seasonal to multidecadal scales provide relevant information on

In this report

Awardees research profiles

Figure 1: Header picture of the 53rd Liège Colloquium and 3rd GO_2NE open conference on ocean deoxygenation: Low oxygen environments in marine and coastal waters.

the physical and biogeochemical functioning of the ocean, and often acts to constrain life in the ocean.

Current evidence indicates that the coastal (i.e., most directly influenced by land) and open ocean areas have been losing O_2 since the middle of the last century, with consequences for living organisms and biogeochemical cycles that are not yet fully understood. In the open ocean, the O_2 inventory has decreased by a few percent (i.e., 0.5-3%) and Oxygen Minimum Zones (OMZs) are expanding, which is primarily attributed to global warming although a quantitative understanding is still lacking. The number of hypoxic coastal sites has increased, predominantly in response to worldwide eutrophication; yet trends in deoxygenation in the global coastal zone remain ill-defined.

The development and extension of areas with low O_2 concentrations degrade the living conditions and contract the metabolically viable habitat for a large number of pelagic, mesopelagic, and benthic organisms. The effects on individuals exposed to low O_2 can result in altered food web structures.

Deoxygenation affects many aspects of the ecosystem services provided by the ocean and coastal waters. For example, deoxygenation effects on fisheries include low O_2 affecting populations through reduced recruitment and population abundance, as well as through an altered spatial distribution of the harvested species, which can cause changes in fishing activity. These effects can lead to changes in the profitability of the fisheries and can affect the interpretation of the monitoring data leading to misinformed management advice.

Model simulations for this century project a decrease in O_2 under both, high and low CO_2 emission scenarios, while the projections of the coastal ocean at the land-ocean interface indicate that eutrophication will likely continue in many regions of the world. Warming is expected to further amplify deoxygenation in coastal areas. The reason for this amplification is an increased eutrophication that is caused by enhanced and extended stratification.

The Colloquium offered 13 keynote talks, 89 talks, and 60 posters. The presentations highlighted new developments and insights related to deoxygenation in open and coastal waters across 10 thematic sessions (*Ecosystem Services, Translating Science to policy and management; *Deoxygenation and ocean life; *How the past can inform the future?; *Microbial Communities and their controls on biogeochemical feedbacks and interactions; *Deoxygenation in a multi-stressors world; *Observing and modelling deoxygenation; *Deoxygenation, Water quality and the climate system: Understanding processes and feedbacks and developing actionable indicators; ⁎Open ocean and coastal deoxygenation: assessing variability and trends; ⁎Deoxygenation: understanding causes and attributing changes). The Colloquium also involved mentoring activities and 4 panels on “Science to policy”, “Citizen Science”, “Diversity and Equity in STEMS”, and “Communication to the media”.

Contributions from the 53rd Liège Colloquium will be published in a Special Issue of *Biogeosciences*. Full information on the event is available at https://www.ocean-colloquium.uliege.be/ and on Twitter at: https://twitter.com/liegeocean & https://twitter.com/GOOD_Ocean_Oxy.

The Colloquium in numbers:

Participants: 263 in total, 183 on-site, 80 online
Women: 45% of the total, 22% as keynote speakers, 78 % as panelists.

Key messages included the following:

1. The European Union (EU) mission for oceans offers a fantastic opportunity to connect, align and harmonize efforts on deoxygenation to ensure a healthy ocean by 2030. For instance, many national alliances have taken place in the Atlantic – demonstrating collaborative advantages (aligning resources, combining expertise).
2. Take any opportunity to augment our observational capacity and data collection while ensuring data are properly processed, quality controlled/flagged and archived in international databases respecting the Findable, Accessible, Interoperable, and Reusable (FAIR) principles. The building of data synthesis products will help to support the deployment of the Blue Economy in a sustainable way and meet EU policy objectives. The EU Digital Twin (by 2024) will allow visualization of ocean problems and stimulate initiatives on ocean observation to support the policy-making process. The organisation of Hackathons allows linking with the community of data scientists.
3. A crucial challenge is to efficiently communicate about deoxygenation. The community needs strong communicators to bring the issue and its urgency to politicians. Getting the topic of oxygen into policy requires capturing the interest of policymakers on global, regional, national and local scales. Oxygen as a planetary boundary can provide motivation.
4. The philanthropic and private sectors have much to contribute in bringing science to action, with opportunities via companies that have made net zero carbon commitments. They often do not have the direction for action. The UN Ocean Decade, and in particular the Global Ocean Oxygen Decade programme, provides an opportunity to activate blue sectors of the economy and connect with wider interests in ocean health.
5. The young generation can contribute to the worldwide data collection and share efforts around oxygen and other biogeochemical variables, the Early GOOD emerging network will play this vector role.

Authors

Marilaure Grégoire, University of Liège, Belgium
mgregoire@uliege.be

Véronique Garçon, CNRS/LEGOS, France
veronique.garçon@legos.obs-mip.fr

Event sponsors

Francesco Saltalamacchia got a Bachelor degree in Environmental Sciences and a Master degree in Marine Ecology in Italy. He joined the Swedish University of Agricultural Sciences, Sweden, for his Master's thesis in 2018 and then stayed until 2020. His PhD project at the University of Bergen, Norway, aims to assess how water deoxygenation affects the life history and physiological traits of mesopelagic fish.

Life in oxygen-poor environments: growth and life history of the glacier lanternfish (*Benthosema glaciale*) in West Norwegian fjords

Saltalamacchia, F.*, Solås, M.R., Folkvord, A., Salvanes, A.G.V.

Department of Biological Sciences, University of Bergen, Norway

*francesco.saltalamacchia@uib.no

Dissolved oxygen (DO) concentrations in coastal waters have decreased drastically in the last few decades, and oxygen depletion is now a chronic issue in many areas (Diaz & Rosenberg 1995). Due to the synergistic effect of global warming, organic pollution and eutrophication, coastal hypoxia has in fact shifted from being a local and seasonal natural phenomenon to a major threat to marine ecosystems worldwide (Diaz & Rosenberg 2008). Hypoxia has been linked to shifts in the composition of ecological communities (Domenici *et al.* 2017), disruption of life cycles, reduced growth (Tunnicliffe *et al.*, 2020), impairment of reproduction (Wu, 2009) and change of migration patterns due to habitat loss (Ludsin *et al.*, 2009). Not all the aquatic organisms, however, respond in similar ways. Since hypoxia originates as a natural phenomenon, species show tolerance thresholds and have developed several strategies to deal with it. Organisms characterised by a greater capacity for oxygen extraction can therefore maintain a routine metabolic rate at lower DO levels, thus exploiting more variable environments. Pelagic organisms are generally considered less vulnerable than benthic ones because they can detect and actively avoid hypoxic layers by moving vertically or horizontally into better-oxygenated waters. This spatial shifting, however, may lead to a decoupling of the spatial distribution of predators and preys, since species in different trophic levels may have different tolerance thresholds to low-oxygen conditions

The mesopelagic domain (or “twilight zone") extends from the bottom of the photic zone to the deepest layers penetrated by light, with a depth range typically considered to be between 200 and 1000 meters below the surface. The biomass of mesopelagic organisms, estimated in the order of 10 billion tons globally, has been proposed as a potentially harvestable resource (Lam & Pauly 2005), especially considering the poor status of worldwide fisheries and the continued increase in the human population. Mesopelagic species are also important components of pelagic food webs, and with their diel vertical migrations, they play a vital role in transporting organic matter between the surface and deeper layers of the water column (Bianchi *et al.*, 2013).

Using Norwegian fjords as a model environment, this work aimed to assess whether low-oxygen conditions affect growth, vertical distribution, and body condition of one of the most abundant mesopelagic fish species in the North Atlantic, the glacier lanternfish *Benthosema glaciale*. The basin water of Masfjorden, on the west coast of Norway, was continuously hypoxic from 2016 to 2020. Environmental data and biological samples were collected at fixed depth intervals over several years in Masfjorden (before, during, and after hypoxia) and in a neighbouring well-oxygenated fjord. The Von Bertalanffy's growth parameters from Masfjorden did not differ between 2017, 2020 and 2021, and were not significantly different from what was observed in Fensfjord in 2020 (Figure 2). Length distributions by depth intervals showed an increase in mean lengths through time in Masfjorden, suggesting individuals' upward movement from the hypoxic layer into more oxygenated waters (Figure 3). Both length-weight relationship and body condition modelled against

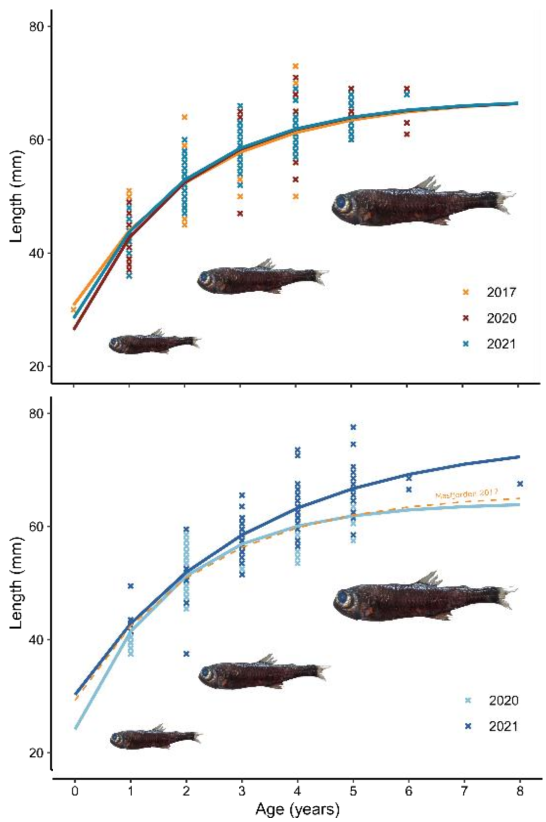

Figure 2: Standard length at age, and estimated Von Bertalanffy growth curves for the sampled populations of *B. glaciale*. Top: Masfjorden 2017 (hypoxic), 2020 (low oxygen) and 2021 (well oxygenated). Bottom: Masfjorden 2017 (hypoxic), and Fensfjorden 2020 and 2021 (well oxygenated).

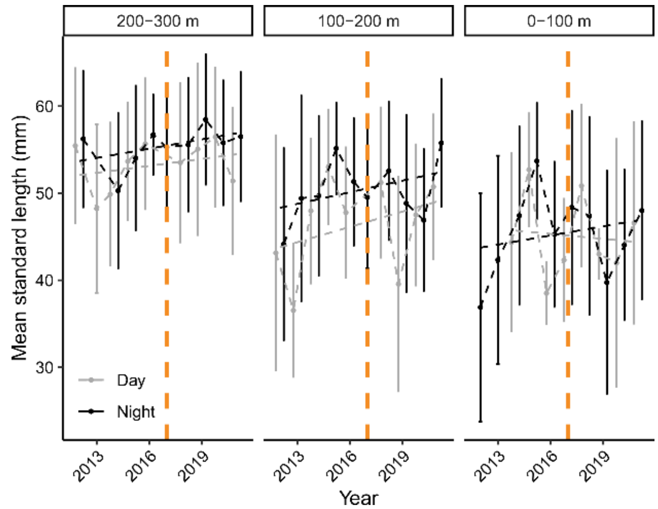

Figure 3: Mean standard length of *B. glaciale* through time (2012-2021) over three depth intervals (200-300 m, 100-200 m and 0-100 m) in Masfjorden. Day samples are shown in grey, night samples in black.

oxygen concentration showed slightly skinnier fish in the deepest sample collected from Masfjorden during the year with the lowest dissolved oxygen levels.

Ocean warming and oxygen loss are pressing concerns in coastal areas. Fjords are particularly vulnerable since stratification limits the renewal of deep basin water at sill depth and therefore the supply of dissolved oxygen. Although highly-abundant mesopelagic fish is regarded as a potential food resource for the future, their susceptibility to global change is yet to be assessed. Our preliminary results suggest that the depth distribution of the glacier lanternfish might be altered due to hypoxic conditions, with the larger individual (normally dwelling in deeper waters) migrating upwards. Moreover, body condition at greater depths also appears unfavourably affected.

References

Bianchi, D, Galbraith, E.D., Carozza, D.A., *et al*. (2013). Intensification of open-ocean oxygen depletion by vertically migrating animals. *Nat. Geosci.*, 6, 545-548. https://doi.org/10.1038/ngeo1837

Diaz, R.J. & Rosenberg, R. (1995). Marine benthic hypoxia: a review of its ecological effects and the behavioural responses of benthic macrofauna. *Oceanogr. Mar. Biol.*, 33, 245-303. https://www.researchgate.net/publication/236628341341

Diaz, R.J. & Rosenberg, R. (2008). Spreading dead zones and consequences for marine ecosystems. *Science*, 321(5891), 926-929. https://doi.org/10.1126/science.1156401

Domenici, P., Steffensen, J.F. & Marras, S. (2017). The effect of hypoxia on fish schooling. *Phil. Trans. R. Soc. B*, 372, 20160236. http://dx.doi.org/10.1098/rstb.2016.0236

Lam, V., & Pauly, D. (2005). Mapping the global biomass of mesopelagic fishes. *Sea Around Us Project Newsletter*, 30(4), 4. https://bit.ly/3zr5WKc

Ludsin, S.A., Zhang, X., Brandt. S.B., *et al.* (2009). Hypoxia avoidance by planktivorous fish in Chesapeake Bay: Implications for food web interactions and fish recruitment. *J. Exp. Mar. Biol. Ecol.*, 381, S121-S131. https://doi.org/10.1016/j.jembe.2009.07.016

Tunnicliffe, V., Gasbarro, R., Juanes, F., *et al.* (2020). An hypoxia - tolerant flatfish: consequences of sustained stress on the slender sole *Lyopsetta exilis* (Pleuronectidae) in the context of a changing ocean. *J. Fish Biol.*, 96(2), 394-407. https://doi.org/10.1111/jfb.14212

Wu, R.S.S. (2009). Effects of hypoxia on fish reproduction and development. *Fish physiology*, 27, 79-141. https://doi.org/10.1016/S1546-5098(08)00003-4

Acknowledgements

I would like to thank SOLAS for providing the funding that facilitated my attendance at the 53rd International Colloquium on Ocean Dynamics in Liège, Belgium (May 2022).

Martine Røysted Solås completed her Bachelor's degree in biology and Master's degree in marine biology at the Department of Biological Sciences, University of Bergen in Norway. In 2019, she started her PhD at the same department to investigate how mesopelagic organisms will respond to hypoxia in Western Norwegian fjords.

Light environment and vertical distribution of mesopelagic organisms in poorly- and well-oxygenated Norwegian fjords

Solås, M.R.*[1,2], Aksnes, D.L.[1], Staby, A.[3], Salvanes, A.G.V.[1,2]

[1] Department of Biological Sciences, University of Bergen, Norway
[2] Bjerknes Centre for Climate Research, Norway
[3] Institute of Marine Research, Norway

*martine.solas@uib.no

Every diel cycle, large masses of small pelagic fish and crustaceans undertake diel vertical migrations following daily variations in sunlight. These assemblages of organisms are often referred to as sound scattering layers (SSLs) because they appear as acoustically dense layers when viewed using an echosounder. The SSLs are ubiquitous in the world's oceans and their migration behaviour contribute to active transport of carbon between surface waters and the deep ocean (Davison *et al.*, 2013). The SSL organisms have key roles in the marine food web and with the growing interest in harvesting also these species (St. John *et al.*, 2016), it has become important to expand our knowledge of how these organisms might be influenced by anthropogenic pressures such as the ongoing ocean deoxygenation (Breitburg *et al.*, 2018).

The deep daytime depth of the SSLs is known to be related to water mass light penetration, where murky water leads to a shallower daytime depth than clear water (Røstad *et al.*, 2016). Research has also found that shallower SSL daytime depth can concur with hypoxia. Some suggest that shallower daytime depths are a result of SSL organisms avoiding low-oxygen water (Bianchi *et al.*, 2013; Netburn & Koslow, 2015) while others have found that hypoxic water masses seem to have reduced light penetration compared to well-oxygenated water (Aksnes *et al.*, 2017).

In this PhD project (which is part of the HypOnFjordFish research project) I use Western Norwegian fjords with different oxygen conditions to study how deoxygenation might influence mesopelagic organisms and SSL characteristics. Part of this work is also to explore the hypothesis of a negative correlation between dissolved oxygen and light attenuation. Preliminary findings were presented during the 53rd International Colloquium on Ocean Dynamics (GO$_2$NE 3rd Oxygen conference) (Figure 4). The next steps are now to investigate the vertical distribution and migration pattern of the SSL organisms in the fjords, using echo sounders and trawl hauls, to see how their daytime depth and vertical migration relate to the oxygen and light environment.

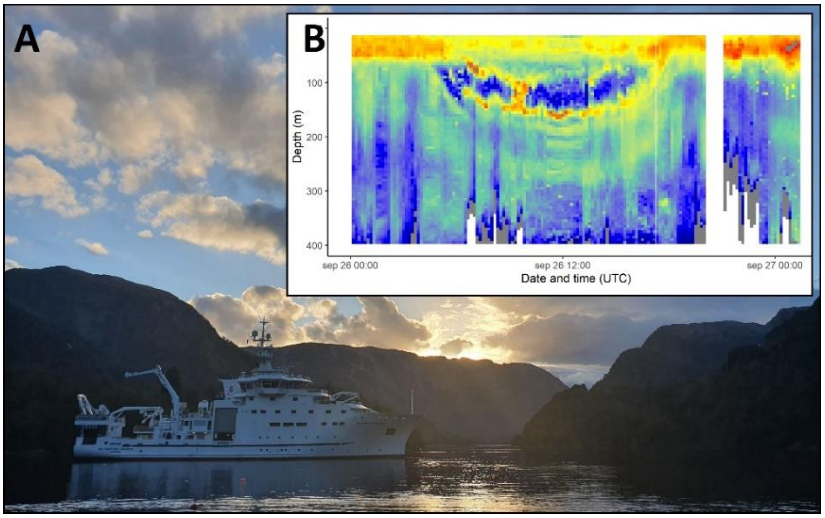

Figure 4: A: Photo of the research vessel Dr. Fridtjof Nansen in inner Masfjord. B: Example echogram from a fjord illustrating diel vertical migration by sound scattering layers (warmer colours indicate higher densities of organisms) over a diel cycle (Solås *et al.*, unpublished).

References

Aksnes, D.L., Røstad, A., Kaartvedt, S., et al. (2017). Light penetration structures the deep acoustic scattering layers in the global ocean. *Sci. Adv.*, 3(5), e1602468. https://doi.org/10.1126/sciadv.1602468

Bianchi, D, Galbraith, E.D., Carozza, D.A., *et al*. (2013). Intensification of open-ocean oxygen depletion by vertically migrating animals. *Nat. Geosci.*, 6, 545-548. https://doi.org/10.1038/ngeo1837

Breitburg, D., Levin, L.A., Oschlies, A., et al. (2018). Declining oxygen in the global ocean and coastal waters. *Science*, 359, eaam7240 https://doi.org/10.1126/science.aam7240

Davison, P.C., Checkley Jr., D.M., Koslow, J.A. & Barlow, J. (2013). Carbon export mediated by mesopelagic fishes in the northeast Pacific Ocean. *Prog. Oceanogr.*, 116, 14-30, https://doi.org/10.1016/j.pocean.2013.05.013

Netburn, A.N. & Koslow, J.A. (2015). Dissolved oxygen as a constraint on daytime deep scattering layer depth in the southern California current system. *Deep Sea Research Part I: Oceanographic Research Papers*, 104, 149-158. https://doi.org/10.1016/j.dsr.2015.06.006

Røstad, A., Kaartvedt, S. & Aksnes, D.L. (2016). Light comfort zones of mesopelagic acoustic scattering layers in two contrasting optical environments. *Deep Sea Research Part I: Oceanographic Research Papers*, 113, 1-6. https://doi.org/10.1016/j.dsr.2016.02.020

St. John, M.A., Borja, A., Chust, G., *et al.* (2016). A dark hole in our understanding of marine ecosystems and their services: Perspectives from the mesopelagic community. *Front. Mar. Sci.*, 3, 31. https://doi.org/10.3389/fmars.2016.0 0031

Acknowledgements

We thank the Research Council of Norway and the Meltzer Research Fund for funding the research and SOLAS for the grant to attend the 53rd International Colloquium on Ocean Dynamics.

Figure 5: Martine was holding the prize for the Best Poster Award © Veronique Garçon

Subhadeep Rakshit studied geological sciences in India and moved to Canada in 2017 to conduct his PhD studies in marine biogeochemistry. Subhadeep started his PhD study at Dalhousie University to investigate the benthic-pelagic coupling of oxygen and nutrients in the seasonally hypoxic coastal basin.

Quantifying oxygen dynamics in a seasonally hypoxic fjord using a coupled benthic-pelagic model

Rakshit, S.[1]*, Davis, R.[1], Wallace, D.[1], Dale, A.[2], Algar, C.[1]

[1] Dalhousie University, Halifax, Canada
[2] GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany

*subhadeep.rakshit@dal.ca

Climate change induced deoxygenation of the world oceans has been occurring over at least the last half century and is further exacerbated in coastal areas by anthropogenic nutrient loading and eutrophication (Diaz & Rosenberg, 2008). Most susceptible to these effects are coastal regions with restricted circulation such as semi-enclosed coastal bays, estuaries, and fjords (Breitburg *et al.*, 2018). Predicting hypoxia and anoxia in these environments involves correctly quantifying oxygen resupply to the bottom water and consumption due to respiration in both the water column and sediments. To determine this oxygen budget, we focus on Bedford Basin, a 70-meter-deep, seasonally hypoxic semi-enclosed fjord on the West Atlantic coast (Nova Scotia), that is connected to the Scotian shelf water through a narrow 20-meter-deep sill, that restricts the exchange and mixing of bottom and surface waters. Bottom water re-oxygenation occurs due to convective winter mixing, and infrequent intrusions of Scotia shelf water during the summer and fall (Haas *et al.*, 2021). The site hosts a time-series station, maintaining weekly hydrographic measurements for two decades (Bedford Institute of Oceanography, 2014). Here, we constructed a 1-Dimensional coupled benthic-pelagic model describing the oxygen dynamic of the basin bottom waters. The model was constrained with conductivity, temperature and depth (CTD) sensors data from ongoing monitoring of basin, and sediment oxygen uptake that we determined from seasonally collected sediment cores using Clark type microsensors (Figure 6). The model reproduced seasonal changes in bottom water oxygen, sediment oxygen penetration depths (measured using Clark microelectrodes), and benthic oxygen fluxes. We found that

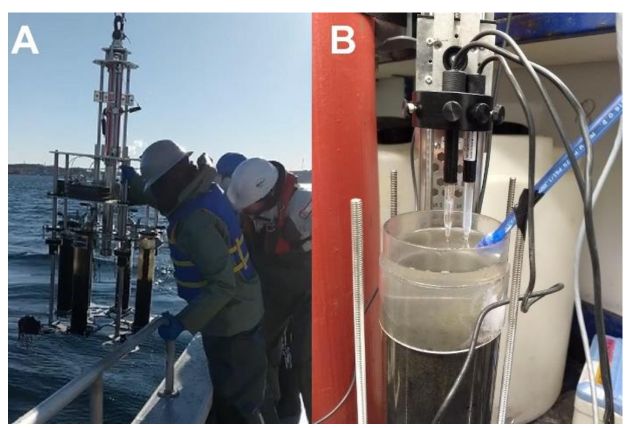

Figure 6: A. Collecting sediment cores using the multicore. B. Measuring oxygen concentration profiles in the sediments, using Unisense microsensors in the cold-room after bringing the cores to the lab.

the bottom water (below sill depth water) re-oxygenation occurs majorly due to convective winter mixing, and infrequent intrusions of Scotia shelf water during the summer and fall, nevertheless, the stratified time supply of oxygen to the bottom water is considerable and depends on the degree of sea surface temperature. This often determines the intensity of bottom water hypoxia that takes place in Bedford Basin in late summer and fall. We also found that intrusions in Bedford Basin happen rapidly in a timescale of a few hours and substantially change the water mass, which could introduce oxygen in a comparable amount to winter mixing, and often terminates hypoxia. Such a model framework can be used as a tool to assess the sensitivity of coastal hypoxia to climate induced changes (i.e. increased stratification and temperatures), oxygen resupply and consumption processes, as well as nutrient dynamics.

References

Breitburg, D., Levin, L.A., Oschlies, A., et al. (2018). Declining oxygen in the global ocean and coastal waters. *Science*, 359, eaam7240 https://doi.org/10.1126/science.aam7240

Diaz, R.J. & Rosenberg, R. (2008). Spreading dead zones and consequences for marine ecosystems. *Science*, 321(5891), 926-929. https://doi.org/10.1126/science.1156401

Haas, S., Robicheau, B.M., Rakshit, S., et al. (2021). Physical mixing in coastal waters controls and decouples nitrification via biomass dilution. *Proc. Natl. Acad. Sci. U. S. A.*, 118(18), e2004877118. https://doi.org/10.1073/pnas.2004877118

Bedford Institute of Oceanography (Ed.) (2014). *The state of phytoplankton and bacterioplankton at the Compass Buoy Station: Bedford Basin Monitoring Program 1992-2013*. Fisheries and Oceans Canada. https://bit.ly/3J1eIC4

Acknowledgements

I would like to thank SOLAS for providing the travel grant to attend the 53rd International Colloquium on Ocean Dynamics in Liège, Belgium. Additionally, I thank Nova Scotia Graduate Scholarship, and Transatlantic Ocean System Science and Technology graduate school, Natural Sciences and Engineering Research Council of Canada (NSERC) and Ocean Frontier Institute (OFI) which supported the research.

SOLAS Sponsors

Contact

SOLAS International Project Office

University of Galway, Ireland
State Key Laboratory of Marine Environmental Science, Xiamen University, China

solas@geomar.de

Editors:
Jessica Gier, Li Li and Chengcheng Gao