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Canada Excellence Research Chair in Ocean Science and Technology

Ocean alkalinity enhancement and mitigation of ocean deoxygenation

Douglas Wallace

Dalhousie University and MEOPAR
Canada

Joint session of the London Convention/Protocol Scientific Groups Science Day, Thursday, 16 March 2023

DALHOUSIE UNIVERSITY *Inspiring Minds*

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Talk outline and take homes:

Ocean Alkalinity Enhancement (an "abiotic" approach to CDR)

- Ocean Alkalininity Enhancement approaches are developing rapidly
- Strong technology "push" from private sector is "pulling" research
- Example of accelerated, coordinated research into monitoring, reporting and verification and impacts
- Urgent need for coordinated, multi-sectoral, transparent, independent research

Mitigation of deoxygenation

- Loss of oceanic oxygen is, arguably, the most dangerous (and overlooked) threat to marine biodiversity and has positive climate feedback potential
- A possibility to mitigate oxygen loss through "ocean reoxygenation" may be about to appear, again from private sector "push"
- Very urgent need for consideration/ research effort/ assessment

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RECENT INCREASED AWARENESS OF OCEAN-CDR (E.G. NASEM REPORT, 2021)

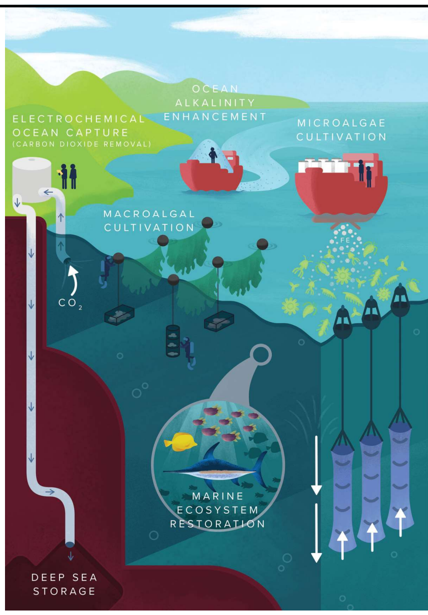
Several options under consideration.
Two fundamental approaches which differ in the components of the marine ecosystem they manipulate.

Carbon Capture Methods:

Photosynthesis (Biotic)

Chemistry (Abiotic)

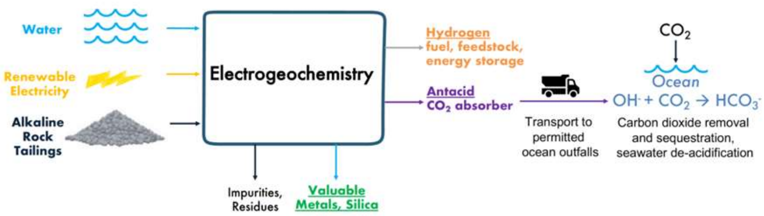
"Framing" of options (e.g. use of the word "nature") can impact social perception and policy.



Graphic © National Academies of Sciences, Engineering, and Medicine. 2021.

PLANETARY

"Planetary Technologies is on a mission to remove 1 billion tonnes of carbon dioxide from the atmosphere by 2045."



Tufts Cove Power Plant, Halifax, Nova Scotia, Canada
Location of an outfall being considered for demonstration OAE addition

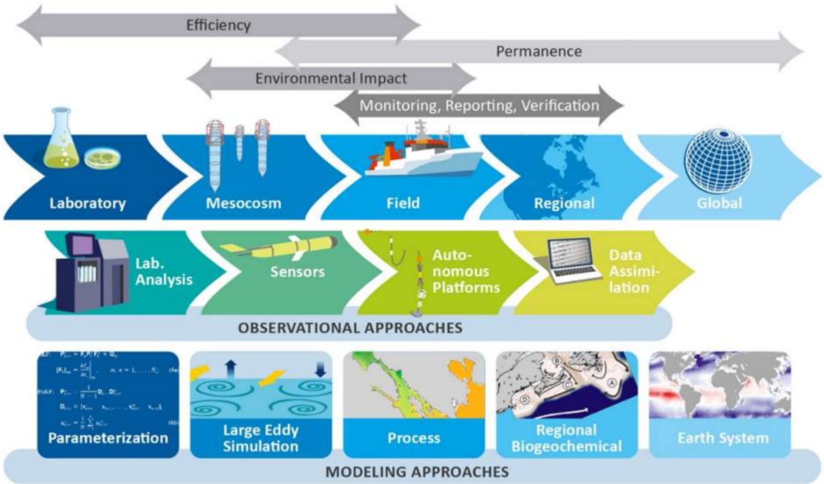
Three field demonstration sites:
St. Ives, Cornwall, UK (underway);
Bedford Basin, Nova Scotia, Canada (2023);
West coast of Canada (TBA)

Addition of $Mg(OH)_2$ in slurry form via wastewater and thermal power plant outfalls initially

Coordinated but independent field experiments, measurement and modelling studies by 3rd parties aimed at MRV and Impacts research
MOVING VERY FAST!! A CHALLENGE TO THE RESEARCH SYSTEM.

How can science respond? What type of science is needed?

ALK-ALIGN. A multi-scale, multi-partner, international and multi-disciplinary research initiative to examine OAE effectiveness and impacts
Dalhousie University (Canada), GEOMAR and Uni-Hamburg (Germany), Univ. Tasmania and Southern Cross University (Australia)



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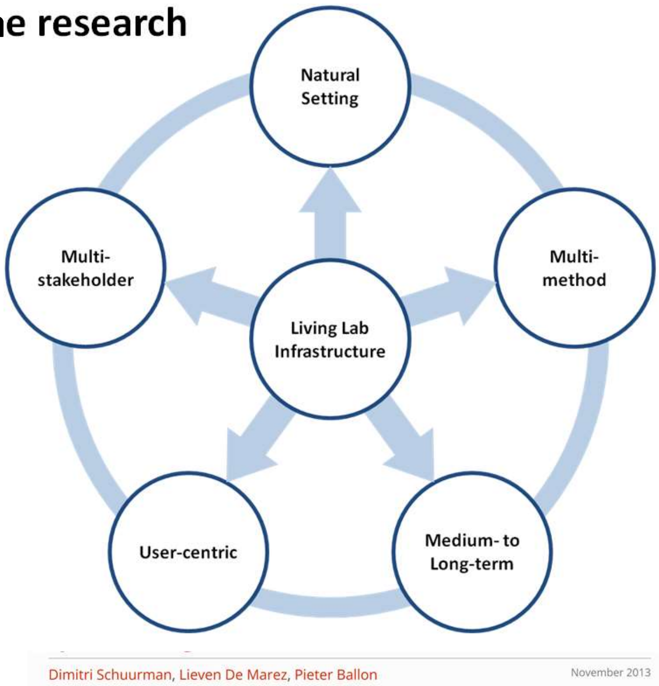
"Living Labs" can form part of the research strategy

- A physical region or virtual reality, or interaction space,
- where companies, public agencies, universities, users, and other stakeholders form public-private-people partnerships (4Ps),
- to collaborate for creation, prototyping, validating, and testing of new technologies, services, products, and systems in real-life contexts

(Westerlund & Leminen, 2011).



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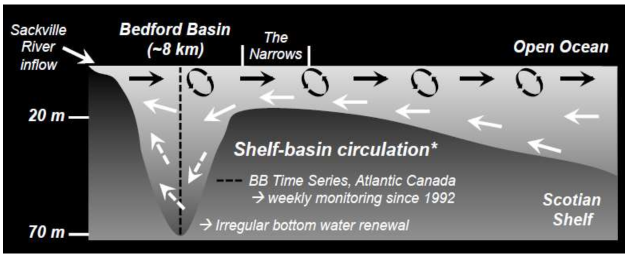
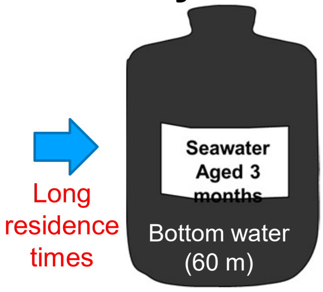
Bedford Basin: a living lab for ocean biogeochemistry?

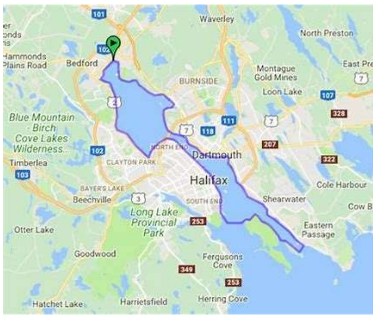




Manageable scale
Inputs/ outputs measurable
MRV may be possible
Experiments can be repeated
Public participation likely

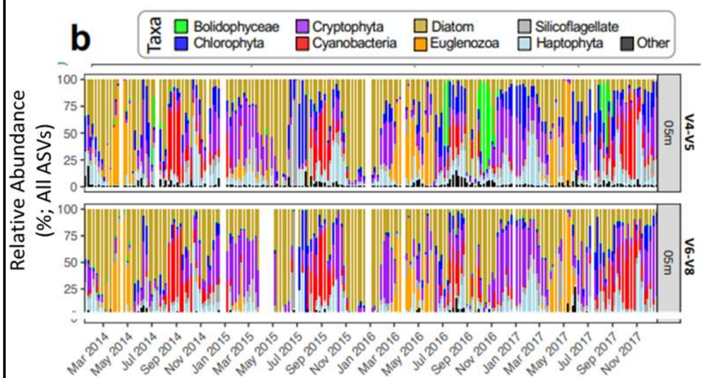
Weekly sampling since 1992

Fisheries and Oceans Canada
Pêches et Océans Canada

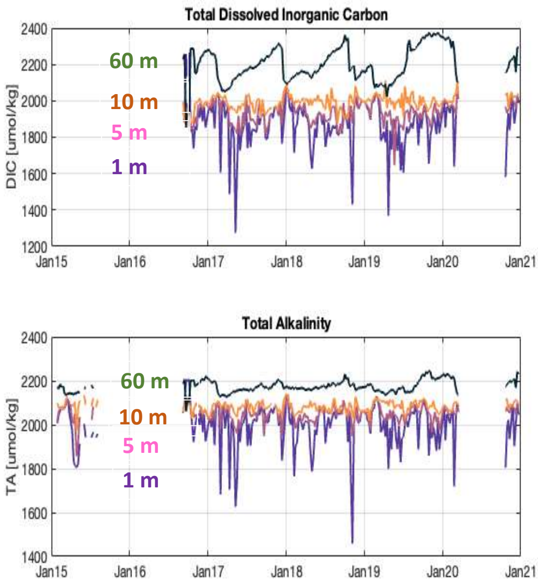


Well-characterized variability

of physical, chemical and microbial parameters
(including alkalinity, DIC, pCO_2, other greenhouse gases, etc.)



Phytoplankton biodiversity representative of open ocean
Bacteria and archaea biodiversity data also available
Robicheau et al., ISME Comms, 2022;



Kumiko Azetsu-Scott, DFO

A useful model framework

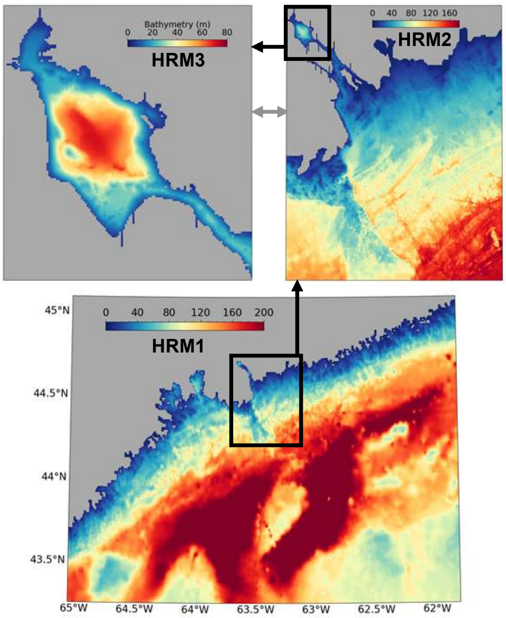
HRM3: Bedford Basin + Narrows
Horizontal resolution: 60 m
Forcing: HRM2 + ERA5
Bathymetry: NONNA

Offline ↑ ↕ **Online**

HRM2: Inner Scotian Shelf
Resolution: ~185 m
Forcing: HRM1 + ERA5
Bathymetry: NONNA

Offline ↑

HRM1: Central Scotian Shelf
Resolution: ~900 m
Forcing: Tides + GLORYS + ERA5
+ BGC climatology (ACM)
Bathymetry: GEBCO
Simulation: 1995 to present ongoing



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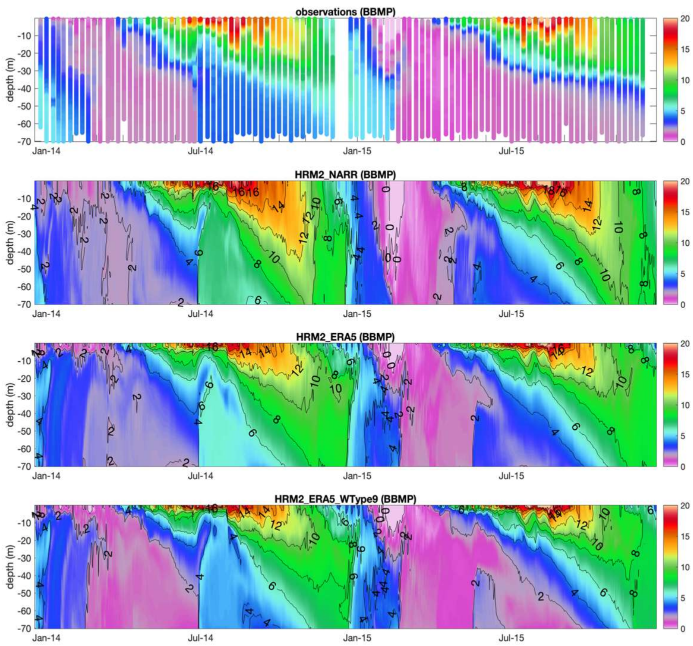
Ability to test and validate models against LOTS OF data



Replacing atmospheric forcing with ERA5

Increasing the water turbidity

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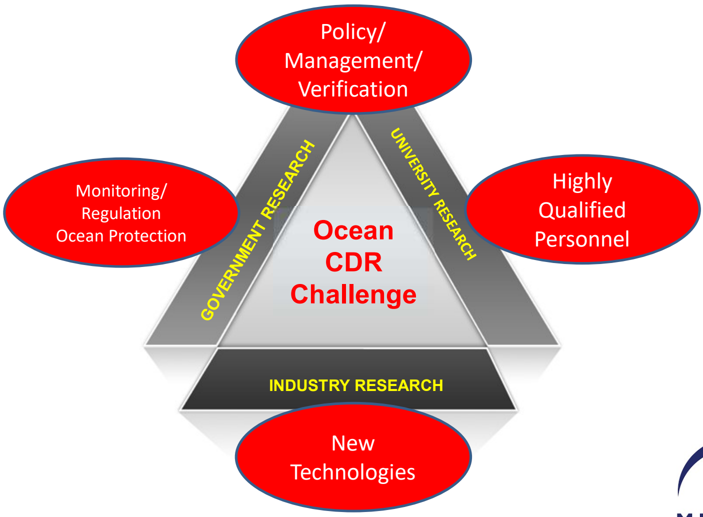
Ability to foster/ support multisectoral research:
Nucleii for multi-sectoral, collaborative research and innovation
Including NGO's, coastal communities



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Cautions and some suggestions:

1) Pace of activity with OAE increasing but largely uncoordinated

"mCDR is emerging …… from innovation projects that pose co-benefits and conflicts between ocean protection, economy, and climate." (Boettcher et al., 2021)

2) Independent funding agencies for research slow to react

3) Need for close combination of modelling and observation to address MRV challenge. This is rare and requires a data rich environment.

4) Public and NGO participation in the research should be encouraged

2) Governance issues:

mCDR's "global commons" dimensions could serve as a springboard for more coordinated international governance.

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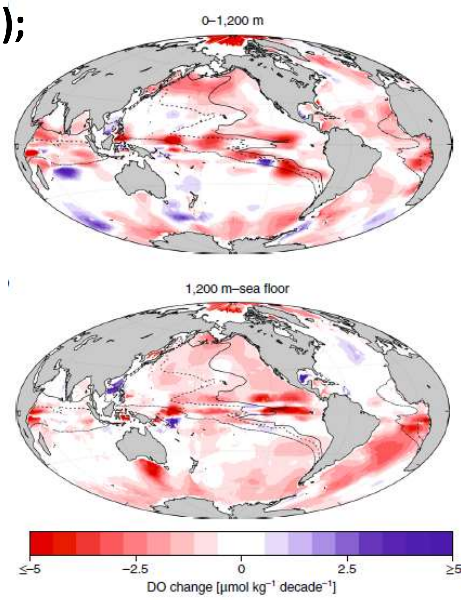
Dissolved Oxygen

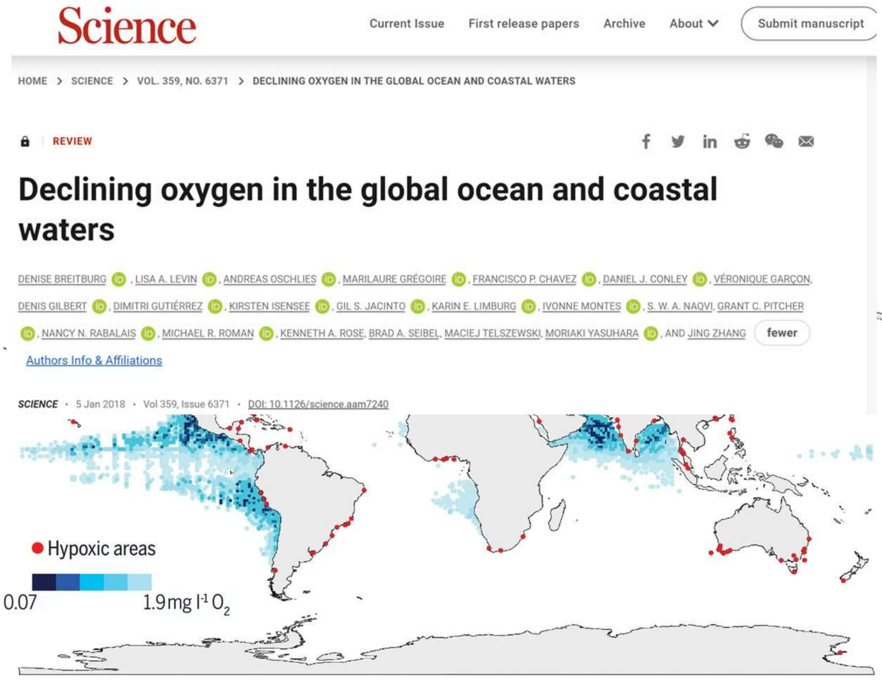
- A soon-to-emerge issue

Ocean Deoxygenation:
2% decrease in O_2 inventory over 50 years;
~75% of O_2 decrease in deep ocean (>1200m);
Δwarming/solubility explains ~15%

Increased respiration/ removal?
Decreased ventilation/ supply?
BGC models have difficulty representing observed trends and patterns

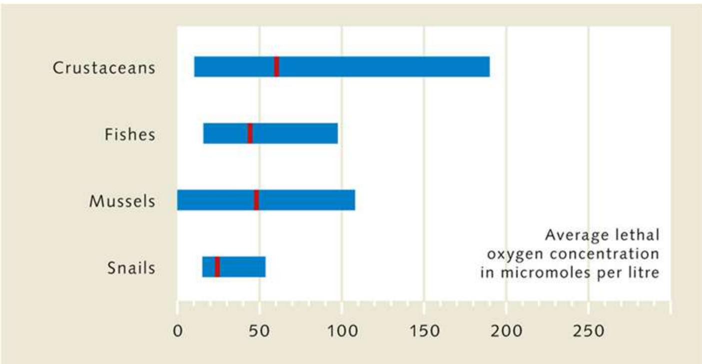


Oschlies et al., Nature Geosci., 2018



Why does "deoxygenation" matter?

1. Oxygen concentration can be a "tipping point" for life in the ocean.



World Ocean Review, 2010

Deoxygenation is a global threat to marine life.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REPORT | EXTINCTION

Avoiding ocean mass extinction from climate warming

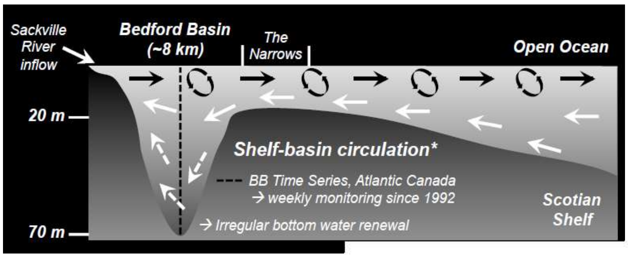
JUSTIN L. PENN AND CURTIS DEUTSCH

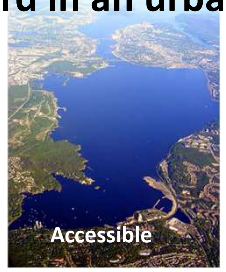
SCIENCE • 28 Apr 2022 • Vol 376, Issue 6592 • pp. 524-526 • DOI: 10.1126/science.abe9039

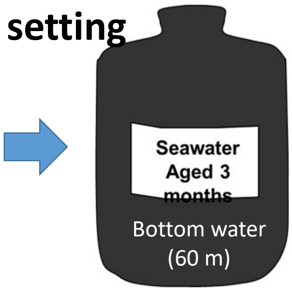
Abstract

…….With accelerating greenhouse gas emissions, species losses from warming and oxygen depletion alone become comparable to current direct human impacts within a century and culminate in a mass extinction rivaling those in Earth's past.
Reversing greenhouse gas emissions trends would diminish extinction risks by more than 70%, preserving marine biodiversity accumulated over the past ~50 million years of evolutionary history.

Climate feedbacks are also a risk.
Bedford Basin: seasonally, hypoxic fjord in an urban setting



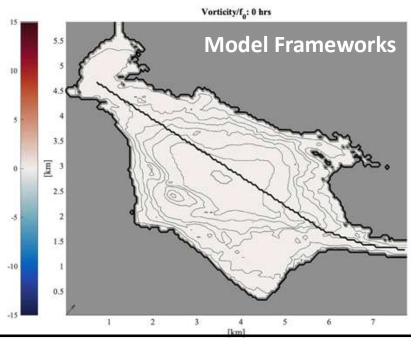


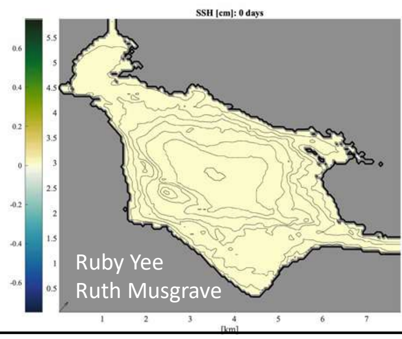


Manageable scale
Inputs/ outputs measurable

Weekly sampling since 1992

Fisheries and Oceans Canada
Pêches et Océans Canada





Bedford Basin: oxygen seasonality

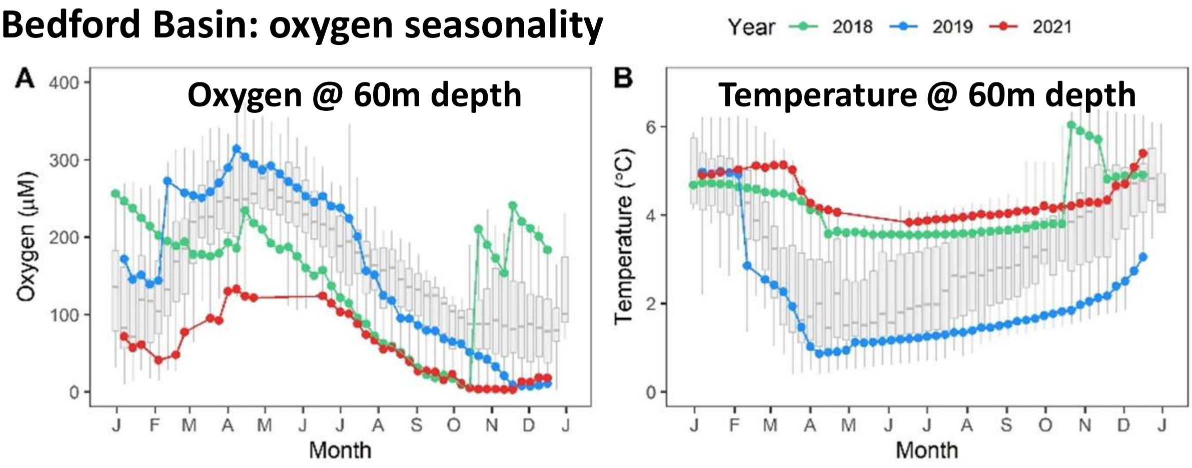


Figure 2: The boxplots represent the climatology of Bedford Basin (2000-2021) and the colored curves show the values for the indicated years derived from weekly CTD deployment at Compass Buoy site.

Subhadeep Rakshit, Andrew W. Dale, Douglas Wallace, Christopher Algar. “Sources and sinks of bottom water oxygen in a seasonally hypoxic fjord”, Submitted to JGR Oceans, 2023

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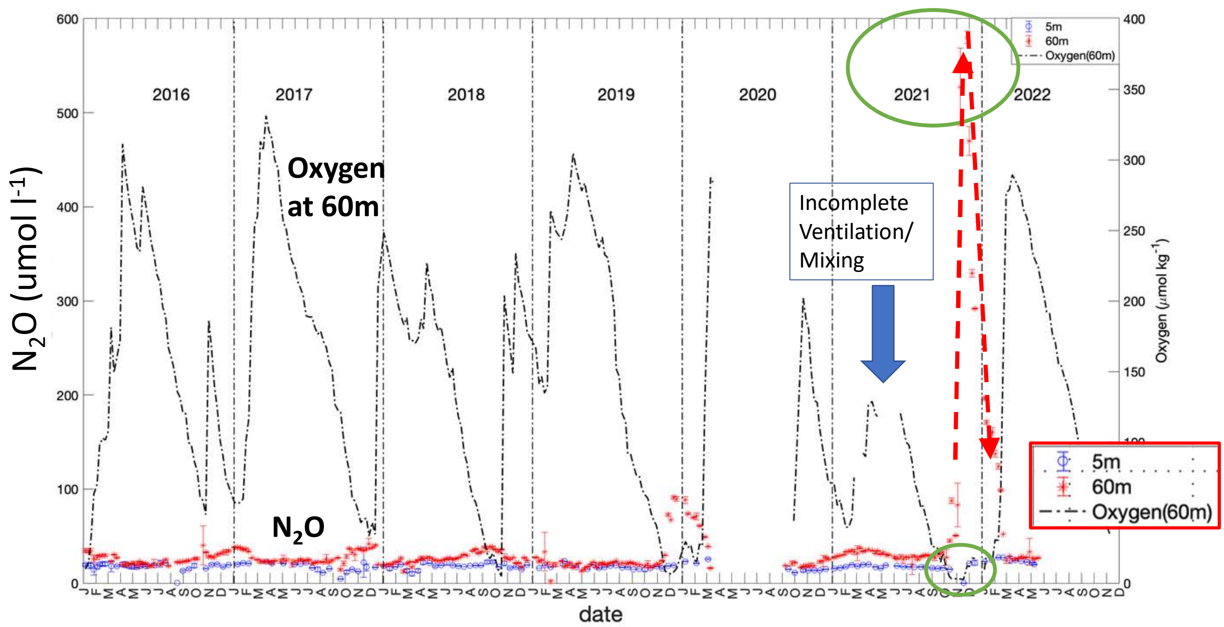
A Climate-change feedback?



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Amount of N_2O Produced due to hypoxia in Winter 2021-2022

- Peak concentration 600 nM (6 x 10^{-4} mol m^{-3})
- 40m thick low-oxygen layer
- Area of Basin >40m depth: ca. 10 km^2 or 10^7 m^2

- Peak Inventory 2.5 x 10^5 moles N_2O or 11 tonnes of N_2O

With GWP of 267 this is equivalent to emission of **3000 tonnes of CO2**

Is enhanced N2O production a sign of things to come?
Warmer winters→ growing hypoxia in coastal regions?
Is mitigation of N2O emissions possible by regulation of oxygen?

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Can the threat of deoxygenation be mitigated?

An analysis from a small Swedish fjord

Continental Shelf Research 244 (2022) 104806
Contents lists available at ScienceDirect
Continental Shelf Research
journal homepage: www.elsevier.com/locate/csr
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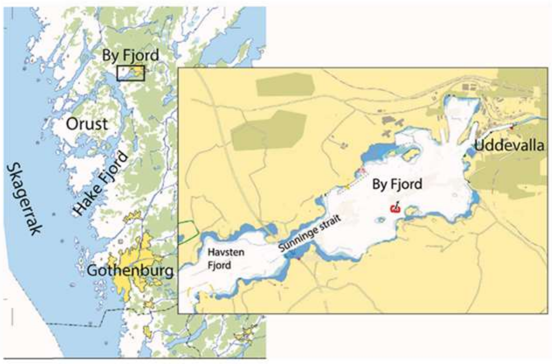
Improving oxygen conditions in periodically stagnant basins using sea-based measures - Illustrated by hypothetical applications to the By Fjord, Sweden

Anders Stigebrandt *, Ambjörn Andersson
Dept of Marine Sciences, University of Gothenburg, Gothenburg, Sweden



Approaches considered:

A. Relocate sewage outfalls; decrease nutrient input
B. Pump oxygen into basin water (“reoxygenation”)
C. Increase turbulent mixing (“stirring”)
D. Pump buoyant water to depth (“artificial downwelling”)
E. Alter topography of fjord to reduce residence time

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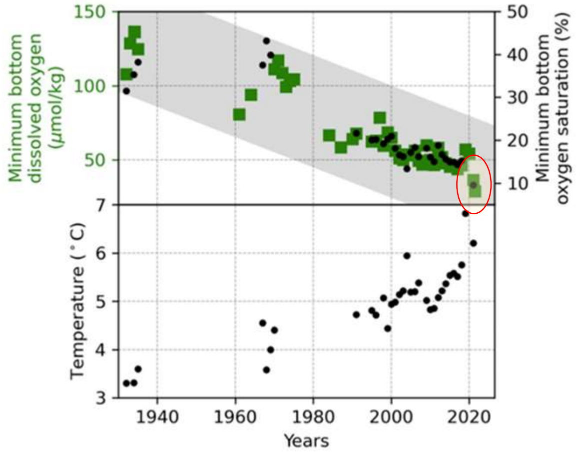
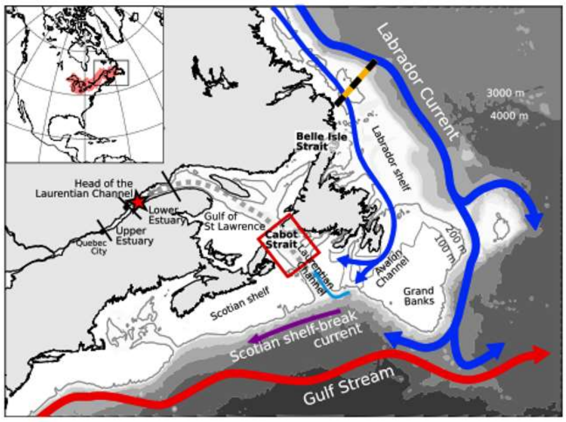
It's not just the deep, open ocean

Oxygen time-series near Rimouski Quebec, Canada
(Head of the Laurentian Channel)





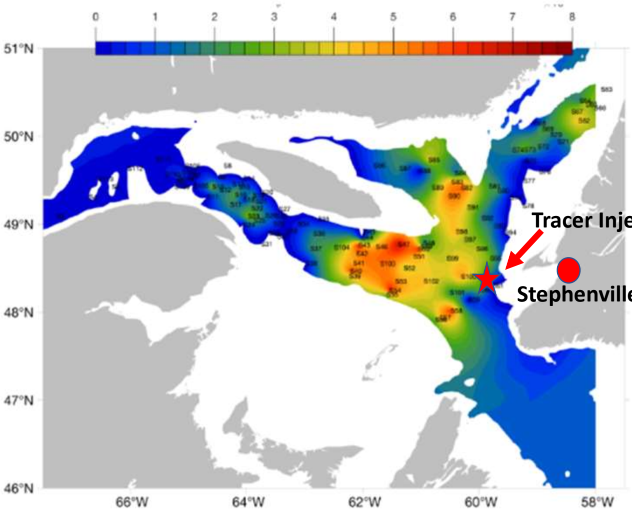
https://doi.org/10.5194/egusphere-2022-1090
Preprint. Discussion started: 20 October 2022

EGUsphere

Temporal and spatial evolution of bottom-water hypoxia in the Estuary and Gulf of St. Lawrence

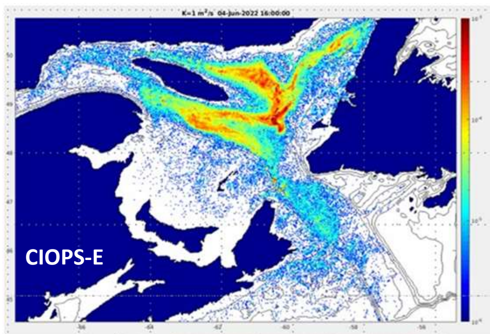
Mathilde Jutras[1,4], Alfonso Mucci[1,5], Gwenaëlle Chaillou[2,4], William A. Nesbitt[3] and Douglas W.R. Wallace[3]

Subsurface spreading of a tracer following injection in October 2021



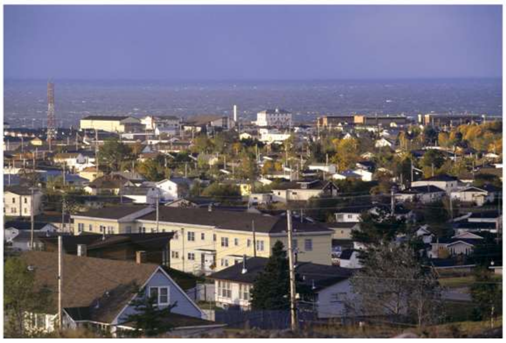
Observed June 2022

CIOPS-E Model prediction for June 2022



Injection of ca. 250 g of SF_5CF_3 (non-toxic; highly inert tracer) at depth of 250 m on σ = 27.26 density surface

Can we (and should we) mitigate deoxygenation?



Stephenville, Newfoundland, Canada

Hydrogen Generation Plant proposed for Stephenville, SW Newfoundland

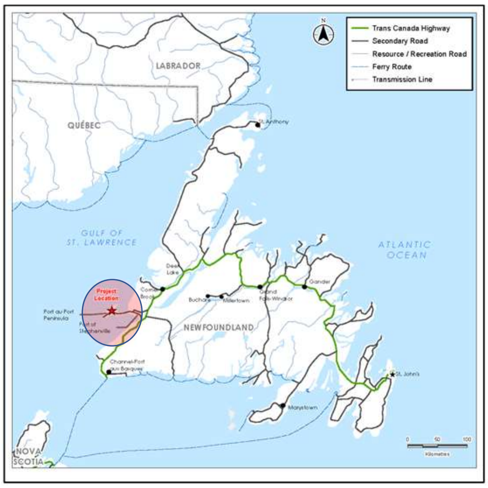


Figure 1-2 Project Location

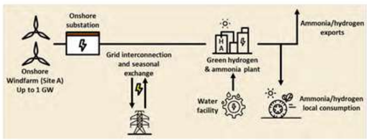
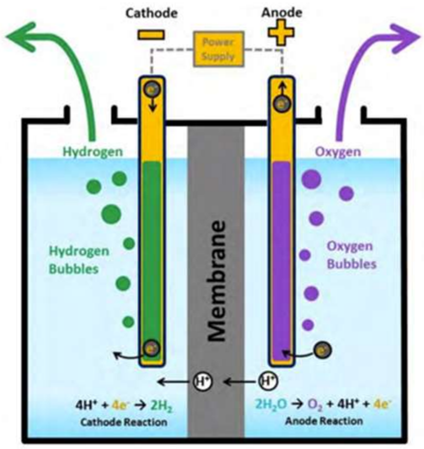


Figure 1-9 Illustration of the Interfaces for Site A Hydrogen Production

Figure 1-5 Overall Project Layout

world energy GH2



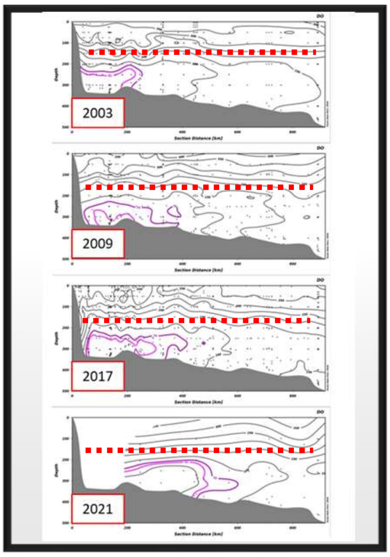
Source: US Department of Energy (DOE)

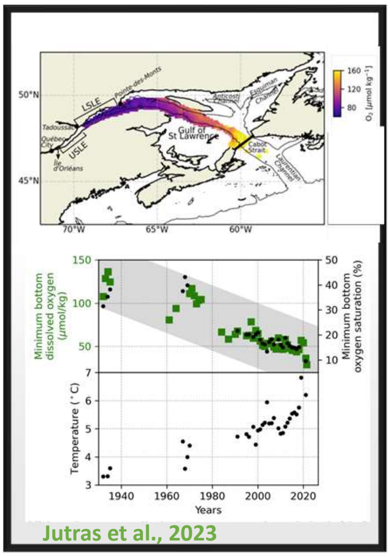
Table 2.7 Oxygen Production Rates

Site A Plant Name-Plate Capacity, MW	Utilization Factor, % Note 1	Max O2 Production, tons per day Note 2	Max O2 Production, tons per annum Note 2
500	100	1,300	480,000
500	50	650	240,000

2.6.4.2 Oxygen Emissions

The plant will emit oxygen to the atmosphere as a byproduct of the electrolysis process; this byproduct will be discharged safely to the atmosphere or captured as a value stream. In the event that a market is identified for the oxygen generated during the process, a capture, storage, and re-use facility will be incorporated into the hydrogen facility.





Average depth: 400 m
LCW/NACW thickness 250 m
Channel length: 850 km
Channel width: 100 km
Volume: 2×10^{13} m^3

Rate of O_2 decline (z>150m):
1-2 mmol m^{-3} yr^{-1}
$2\text{-}4 \times 10^{10}$ mol yr^{-1}

$6\text{-}12 \times 10^5$ tons O_2 yr^{-1}

Production of H_2 plant:
4.8×10^5 tons O_2 yr^{-1}

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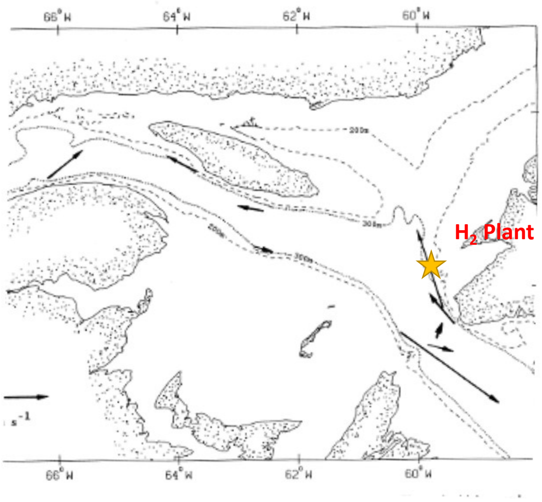
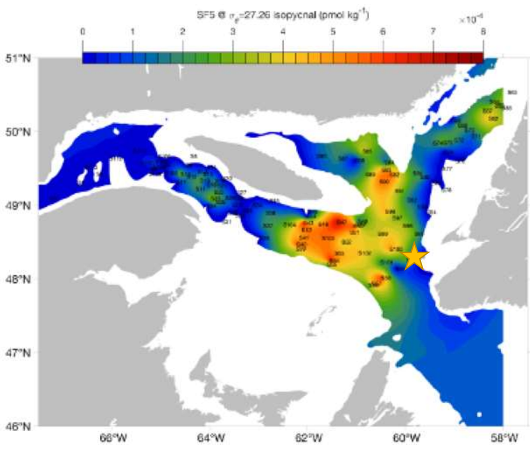
Location, location, location



Average vectors from long-term current meters (Bugden)



Tracer spread from TReX

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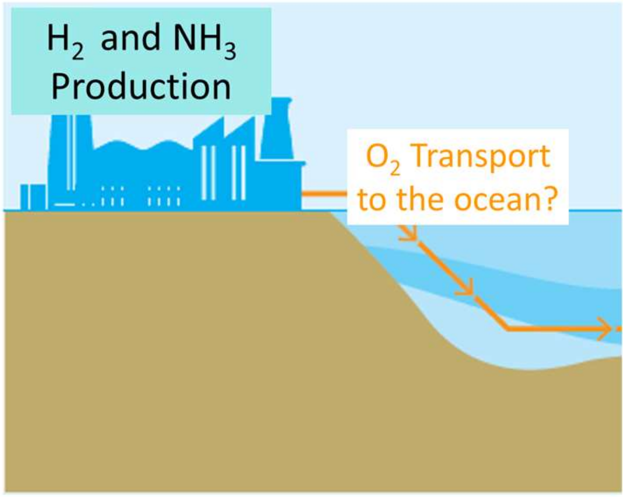
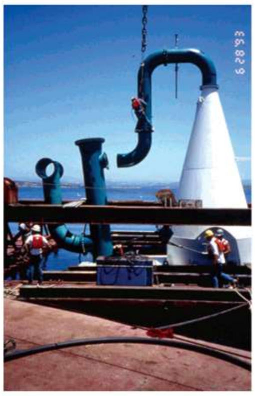
Should "artificial respiration" (reoxygenation) be considered for vulnerable ocean regions/ ecosystems?





Rapid appearance of large quantities of cheap oxygen from the green hydrogen industry, coupled with the threat of deoxygenation to marine biodiversty may motivate schemes to reoygenate parts of the ocean.

Many questions!!

- **Will reoxygenation qualify for biodiversity credits and offsets?**
- **What approaches are effective/ responsible at ocean scale?**
- **Will reoxygenation be effective in mitigating biodiversity loss?**
- **Are there risks?**

Very little is known at present. It's a new topic.