Contribution of nuclear applications to study the effects of reduced oxygen in coastal environments

Peter Swarzenski, François Oberhansli, Simon Pouil, Miguel Gomez, Murat Belivermis & Marc Metian

International Atomic Energy Agency Radioecology Laboratory MONACO
Global warming

- Increase in mean global ocean temperature of 1-4°C by 2100
- Greatest overall ocean warming in the Southern Hemisphere
- Polar regions = 2x the average global warming rate
- Intensification and change in El Niño events (Central Pacific)
- Changes in heat storage, heat transport, and currents
deoxygenation

- Reduced oxygen (O₂) solubility in warmer water.
- Reduced penetration of O₂ into deeper water due to enhanced stratification

**CONTEXT**

2017 Gulf of Mexico Hypoxic Zone Size

Gulf of Oman world’s largest Hypoxic Zone
- Reduced oxygen ($O_2$) solubility in warmer water.
- Reduced penetration of $O_2$ into deeper water due to enhanced stratification observed in much of the global ocean

OM respiration shifts to sp bacteria that use $NO_3$ rather than $O_2$ >> denitrification and $N_2O$ (300x)

More sinking particles reach the deep ocean >> air / sea $CO_2$ partitioning

Warmer water = incr $O_2$ demand
Deoxygenation

Increasing in number, volume, and intensity

<2 mg liter$^{-1}$ (<63 μmol liter$^{-1}$)

Globally distributed

OMZs

Denise Breitburg et al. Science 2018;359:eaam7240
Potential consequences of ocean oxygen loss are profound:
• reduced biological productivity and diversity,
• altered animal behaviour,
• declines in fisheries, redistributions of communities,
• altered biogeochemical cycles, including
• environmental feedbacks (e.g., increased production of N2O and CH4.)
O₂ plays a direct role in the biogeochemical cycling of carbon, nitrogen, and many other biogeochemically important elements: (P, Fe, Mn, etc.)

Low O₂ effects on N and P cycling has global implications

\[ \text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{N}_2\text{O} \rightarrow \text{N}_2 \rightarrow \text{NH}_4^+ \]
O_{2} is also fundamental for all aerobic life, including organisms living in the dark ocean interior.

sensitivity to low DO = non linear

Compounded by CO_{2} and temperature

O_{2} tolerance (LC_{50})
Deoxygenation

Expansion of OMZs and habitat compression impacts commercial fisheries:

- In the tropical Atlantic, blue marlin/tuna have seen a 15% reduction in habitat between 1960-2010 (Stramma et al. 2011)

- Off the US West Coast, the Humboldt squid has greatly expanded its range, and the range expansion coincides strongly with areas of significant oxygen declines (Gilly et al. 2013).
deoxygenation via photosynthesis and respiration

So a tracer of rate at which OM is produced, redistributed, and decomposed in the ocean >> biological pump

O₂ directly linked to carbon
Contribution of nuclear applications to deoxygenation studies

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Contribution of nuclear applications to deoxygenation studies

γ-emitters:
- $^{51}$Cr, $^{54}$Mn, $^{57}$Co, $^{65}$Zn, $^{73}$As, $^{110m}$Ag,
- $^{109}$Cd, $^{134,137}$Cs, $^{203}$Hg, $^{210}$Pb...

β-emitters:
- $^{14}$C, $^3$H, $^{45}$Ca, $^{63}$Ni...

α-emitters:
- $^{210}$Po...

...to assess stress
Contribution of nuclear applications to deoxygenation studies

RADIOTRACERS

Exp. aquaria

HPGe detector

 Gamma spectrum

to assess stress
Regulating DO in experimental aquaria to assess stress
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Oberhänsl et al, in prep
Regulating DO in experimental aquaria

- Able to assess stress at environmental levels
- Very high sensitivity & specificity (multiple isotopes)
- Ability to count live organisms (adjust on the fly)
- Real-time data
- Ability to assess multi-stressor effects
- Cost-effective and easy
Bioconcentration of Zn, Ag, and Cs in mussel (Mytilus edulis)

Low DO on mussels
Filtration rate (L g\(^{-1}\) hr\(^{-1}\)) in mussel (Mytilus edulis)

Ability to feed is reduced with lowered DO

Low DO on mussels
Regulating DO in experimental aquaria

6-d, non-preconditioned experiments show no change in the gross calcification rate with a change in DO

$^{45}$Ca-derived gross calcification rates
Current projects

- Hypoxia
- Microplastics
- Multi-stressors
- Marine carbon
- Black carbon
- MeHg
- HABS
- OA

Radioecology Labs, IAEA Monaco

Boyd et al 2017
The realization that future global warming might significantly impact ocean O2 distributions is still very new...

...so the science of ocean deoxygenation is still in its infancy.