APPROACHES TO ADDRESSING A COMPLEX PHENOMENON IN THE BLACK SEA

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“In situ monitoring of oxygen depletion in hypoxic ecosystems of coastal and open seas, and land-locked water bodies”
(2009-2012)
LONG-TERM CTD SURVEYS
Multidecadal time series & trends
imprint of climate change and eutrophication on pycnocline oxygen

Challenge: to choose the appropriate and most efficient method to addressing the temporal and spatial scales of the phenomenon one wishes to monitor

NORTH-WESTERN SHELF
seasonal bottom water hypoxia

CRIMEAN SHELF - fast oxygen fluctuations at the sediment-water interface

BOSPORUS OUTFLOW
episodic injections of $O_2$ into permanently anoxic deep water

CENTRAL BLACK SEA
persistent suboxic zone & anoxia below pycnocline

mesoscale variability of the oxic-anoxic interface
Central Black Sea: Multidecadal hypoxia trends in stratified basins

APPROACH
Analysis of standard CTD measurements from the last 6 decades

20 – 50 m shoaling of the UBSOZ from 1955 to 2011!

in 1970s and 1980s due to eutrophication, in 1990s and 2000s due to NAO forcing

Mean depth of the upper boundary of the suboxic zone (UBSOZ = 20 µmol O₂ L⁻¹ isopleth)
Multi-decadal time-series data allow separating out the effects of climatic forcing and eutrophication on oxygen depletion. Strong impact of eutrophication while the effect of climate forcing was less pronounced. Long-term monitoring data allow the quantification of spatial and temporal changes in the distribution of oxygen. Projections of climate-driven trends become possible. Long-term monitoring remains crucial for timely warning of dramatic changes.
HYPOXIA PHENOMENA & MONITORING APPROACHES

ARGO (NEMO) FLOATS + O$_2$ OPTODES
continuous 2-dimensional profiles & seasonal trends

mesoscale variability of the oxic-anoxic interface

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Central Black Sea: Areal mesoscale patterns in water column oxygenation

**APPROACH**

ARGO - Navigating European Marine Observer (NEMO) profiling floats (Optimare Sensorsystems) equipped with oxygen optodes (model 3830, AADI), conductivity, temperature, pressure

For the first time in the Black Sea equipped with oxygen optodes!
Central Black Sea: Mesoscale patterns in water column oxygenation

May 2010 until Dec 2011/Nov 2012

NEMO float trajectories
Central Black Sea:
Mesoscale patterns & ARGO floats

- Oxic-anoxic interface varies about 75m in a few weeks, tracks vertical displacement of pycnocline
- “Bursts” of low or high O$_2$ waters demonstrate importance of mesoscale processes for O$_2$ dynamics

Temporal evolution of subsurface oxygen maximum
- reveal short-term to seasonal patterns of water column oxygenation on basin-wide scales

(Stanev et al.)
HYPOXIA PHENOMENA & MONITORING APPROACHES

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**REPEATED FREE-FALLING PUMP-CTD SURVEYS**
high-resolution depth profiles
characterization of oscillating redoxclines & biogeochemical turnover

**HYPOXIA PHENOMENA & MONITORING APPROACHES**
**Bosporus outflow:**
Oxygen intrusions into highly stratified systems

**APPROACH**
Repeated free-falling pump CTD surveys
- In free-falling mode the pump CTD descends slowly along a wire that runs through the center of the instrument
- Sensors for temperature, salinity, and oxygen, and the inlet of the pump, protrude out of the downward-facing cone

Holtappels et al.
Bosporus outflow: Oxygen intrusions into highly stratified systems

**Lateral oxygen intrusions**
- shifts in the position of the oxic/anoxic interface / redoxcline
- mix oxic and reduced compounds, e.g., $O_2$, $NO_3^-$, $H_2S$
- lateral mixing plays a significant role in maintaining a permanent suboxic zone in the Black Sea

- high-resolution profiles suitable for identifying and localizing processes in complex redoxclines
- even in highly stratified systems, redoxclines can be highly complex and dynamic in space and time
HYPOXIA PHENOMENA & MONITORING APPROACHES

NORTH-WESTERN SHELF
seasonal bottom water hypoxia

Static mooring with CTD, DCS, O₂ optodes high-resolution seasonal time series
Assessment of ecosystem recovery

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North-western Black Sea shelf: Seasonal changes in bottom-water oxygen

Drivers of Hypoxia

NATURAL
Seasonal thermohaline stratification due to freshwater-seawater confluence, climate variability

ANTHROPOGENIC
-nutrients from Danube River & non-point sources; eutrophication
-coastal urbanization, agriculture
-overfishing changes foodweb structure

APPROACH
Stand-alone static mooring

RCM9, AADI:
CTD
optical O₂ sensors
doppler current meter
turbidity sensor

Friedrich et al.
North-western Black Sea shelf: Seasonal changes in bottom-water oxygen

3-months deployment (May – August 2010)

absence of thermocline
formation of thermocline
sinking bloom?

Friedrich et al.
HYPOXIA PHENOMENA & MONITORING APPROACHES

CRIMEAN SHELF - fast oxygen fluctuations at the sediment-water interface

STATIC MOORINGS WITH CTD, DCS, O₂ OPTODES
high-resolution time series
Oscillating redoxclines impinging the seafloor

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Drivers - small to large scale processes

- oscillations of chemocline depth (e.g., internal waves, mesoscale eddies, Ekman pumping, atmospheric pressure oscillations and tides)
- locally CH₄ seepage

APPROACH

3 stand-alone static moorings (RCM 9 Aanderaa) at 100m, 135m and 150m depth, measuring temperature, salinity, currents and oxygen, & CTD surveys
Gradual increase in $O_2$ followed by a sudden drop of $O_2$ concentration of more than 150 $\mu$mol L$^{-1}$ within two hours.

Inverse correlation of $O_2$ with density indicative of dynamic shifts of the pycnocline.

Time series of density and $O_2$ at 135m depth.
Decide on the best-suited and most efficient way of resolving the temporal and spatial scales of the phenomenon you wish to monitor.

The processes and scientific questions determine the requirements for the sensors (spatial and temporal resolution, detection ranges, and stability).

Successful assessment of ecosystem conditions depends on the proper selection of monitoring sites, and needs to match periods when hypoxia occurs.

To understand hypoxia drivers requires additional recording of basic physical and biological parameters: application of standard oceanographic and biogeochemical sensors (T, S, p, local currents and profiles, turbidity, and photopigment fluorescence)

Data accessibility by state-of-the-art data-sharing and dissemination procedures, modeling, connect to global earth observation efforts, e.g., EMODnet, GEOSS

Continuation of existing long-term time-series monitoring programs and the set-up of new programs ultimately depends on securing funding & long-term commitments.
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http://www.hypox.net/