Seasonal hypoxia in the Black Sea north-western Shelf.
Is there any recovery after eutrophication?

Arthur Capet, Jean-Marie Beckers, Marilaure Grégoire
Seasonal Hypoxia in the Black Sea
Seasonal Hypoxia

Hypoxic threshold: $[O_2] < 62 \text{ mmol/m}^3 (2 \text{ mg/l})$
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Seasonal Hypoxia

Phytoplankton growth

Respiration

Mixed layer depth

Weak ← Stratification → Strong

Hypoxic threshold: $[O_2] < 62 \text{ mmol/m}^3 (2 \text{ mg/l})$
Seasonal Hypoxia in the BS-NWS

Fig 15. Expansion of seasonal hypoxic and anoxic zones on the north-western shelf (from Zaitsev, 1992a).
Recovery?


5826  7647  981  339
50  127  0  0

Oxygen records
(World ocean atlas, Seadatanet, Black Sea Commission data)

Hypoxic records
(<62 mmol O/m³)
Studying Hypoxia with a 3D model
GHER 3D biogeochemical model

River inputs (nutrients, freshwater, suspended matter)

Atmospheric model & data
GHER 3D biogeochemical model

River inputs (nutrients, freshwater, suspended matter)

Atmospheric model & data

Surface fluxes (heat, momentum, freshwater)

Hydrodynamics → Currents, mixing, T, S

[Maps showing hydrodynamics for different months: April, May, June]
GHER 3D biogeochemical model

River inputs (nutrients, freshwater, suspended matter)

Atmospheric model & data

Surface fluxes (heat, momentum, nutrients, oxygen, freshwater)

Hydrodynamics → Vertical and lateral transport, T°

36 state variables

3 phyto. Groups
4 zoo groups.

C, N, P, Si, O
GHER 3D biogeochemical model

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(nutrients, freshwater, suspended matter)

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C, N, P, Si, O

Photosynthesis, respiration, Bacterial loop, Chemistry

Light penetration

Organic matter deposition.
Resuspension by waves and bottom stress.
Benthic diagenesis → Diffusive fluxes.

(Stanev and Kandilarov, 2012; Soetart, 2000)

Anoxic Chemistry
Benthic Model

Sedimenting variables (POM, Diatoms)

Resuspension due to bottom stress from currents and (mainly) waves.
(Stanev and Kandilarov, 2012)

Benthic remineralisation
Remineralised content (in mmolC/m²/s)
= [fast C stock] \cdot K_{fc} \cdot f(T°)
+ [slow C stock] \cdot K_{sc} \cdot f(T°)

Dynamic fluxes of dissolved matter.
(Stanev and Kandilarov, 2012)

Vertically integrated stocks

<table>
<thead>
<tr>
<th>Labile</th>
<th>C stock</th>
<th>Semi-labile</th>
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<table>
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<tr>
<th>Slow remin.</th>
<th>Si Stock</th>
<th>Fast remin.</th>
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N/C ratio
Model Experiment: 1980 – 2009
Realistic forcings
- Atmospheric: ERAInterim (ECMWF)
- River inputs: Ludwig et al., 2009

15 km grid - 31 vertical levels
Model Validation: Point-to-point

Merged by months → validation of the seasonal cycle

Hypoxic records- [%]
(<62 mmol O/m³)

Hypoxic records: [O₂] – [mmol/m³]

<table>
<thead>
<tr>
<th>Month</th>
<th>Observations</th>
<th>Model</th>
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<tbody>
<tr>
<td>Jan</td>
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<td>Feb</td>
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<td>Nov</td>
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<tr>
<td>Dec</td>
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Number of observations:
- Jan: 61
- Feb: 896
- Mar: 724
- Apr: 1227
- May: 2354
- Jun: 1991
- Jul: 2410
- Aug: 1670
- Sep: 1719
- Oct: 515
- Nov: 756
- Dec: 147
Interannual variability

[Graph showing interannual variability in [O2] or oxygen concentration between 1980 and 2010, with observations and model predictions indicated.]
Interannual

- Observations
- Model @ Observations
- Model: whole domain

Year Range:
- 1980-1987
- 1988-1995
- 1996-2002
- 2003-2009

Data Points:
- 1980-1987: 5826
- 1988-1995: 7647
- 1996-2002: 981
Drivers of interannual variability
Interannual variability of Hypoxia
Interannual variability of Hypoxia

Eutrophication
N : riverine Nitrogen load
C : Accumulation of organic matter in the sediments

Climatic
Ts : Sea surface temperature in early spring
Tf : Sea surface temperature in late summer
Interannual variability of Hypoxia

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\[ H = a_0 + a_N N + a_C C + a_{T_s} T_s + a_{T_f} T_f \]
Hypoxia as a function of N

Includes the year specific influences of climatic and sediments drivers
Hypoxia as a function of N

Includes the year specific influences of climatic and sediments drivers

Average climatic conditions and equilibrated sediments content
Take-home Messages (3)
Take-home Messages (1/3)

Hypoxia is still ongoing in the Black Sea NWS

Monitoring should be focused on the area, months and depth of known hypoxia occurrence.
Take-home Messages (2/3)

Hypoxia is intensified by year-to-year accumulation of organic matter in the sediments.

Systems with decreasing N → inertia in the recovery process.
Systems with increasing N → increase of the H/N ratio. (Turner, 2008)
Take-home Messages (3/3)

Climate impacts almost as much as eutrophication.

Nutrient reduction policies should account for realistic climatic scenarios.
Seasonal hypoxia in eutrophic stratified coastal shelves: mechanisms, sensibilities and interannual variability from the North-Western Black Sea case,

Thank you for your attention.
... and questions!

P. Alechinsky, The Black Sea, 1990
Organic matter accumulates in the sediments

![Graph showing organic matter accumulation over time with blue and red lines representing different models. The graph includes markers for specific years and concentrations.](image-url)
Model Validation: Point-to-point
\[ D = \frac{1}{\max A(t)} \int_{year} A(t) dt, \]
\[ H = \frac{1}{D} \int_{year} A(t) dt, \]
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Recovery?

1980-1987
5826
<2mg/l: 50

1988-1995
7647
127

1996-2002
981
0

2003-2009
339
0

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a) 

b)

Hypoxic areas - [10³ km²]

Mee 2006
present study
UkrSCES 2002

| Selection criteria | All data | $Z > 17$ | $Z > 17$  
|-------------------|----------|----------|----------  
| WOD (1981-2001)   | 14123    | 14088    | 7670       
| Aug., Sep., Oct.  | 3850     | 3847     | 2108       
| BSC (2000-2009)   | 636      | 382      | 86         
| Aug., Sep., Oct.  | 113      | 57       | 8          

The Model

36 States variables

Physics (5)
- Currents, T°, Salinity, Surface elevation, Turbulence

Oxygen and Dissolved Inorganic Carbon (2)

Inorganic nutrients (5)
- SiO, NO3, NH4, PO4, "Reducers"

3 Phytoplankton (6) (free C/N)
- Diatoms, Flagellates, Small Flagellates

Zooplankton (2)
- Micro-, Meso-

Gelatinous zooplankton (2)
- Omnivorous, Carnivorous

Detrital matter (8)
- Particulate, Semi-labile and Labile forms
- Silicious Detritus, Aggregates

Bacteria (1)

Monthly RIVERS fluxes and nutrients flows (from L. Wolfgang & A. Cociasu)

6h-atmospheric forcings from ECMWF (1.125°). (from ERA40)
Model's Specificity

• No data assimilation: Necessity to construct specific Bosphorus representation to ensure conservation of volume and total salt content.

• Anoxic waters: The biological model explicitly includes anoxic chemistry through the use of a variable 'Oxygen demanding Units', as a proxy for reducers acting in the anoxic zone.

• Sediments compartment

• Light absorption scheme