Modelling hypoxia and its impact on marine Good Environmental Status : The Black Sea case

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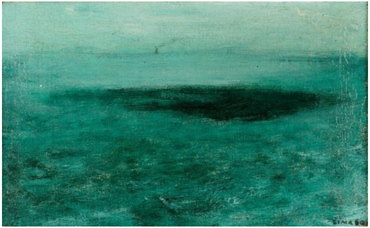
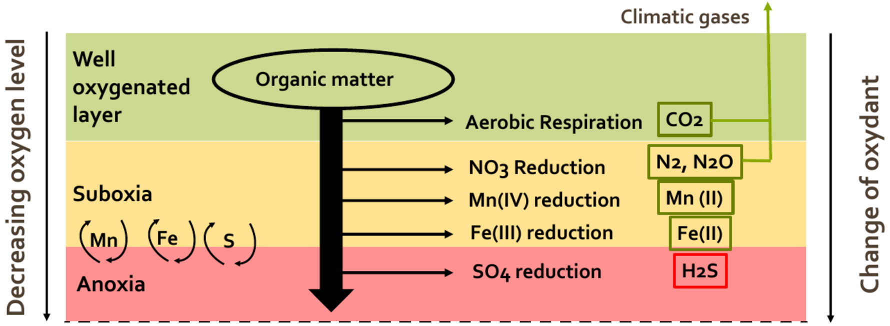
IWMO, Bologna, May 2016



1. Why?
2. Different Morphologies
3. Modelling Challenges
4. The Black Sea case

Oxygen Minimum Zones affects biogeochemistry



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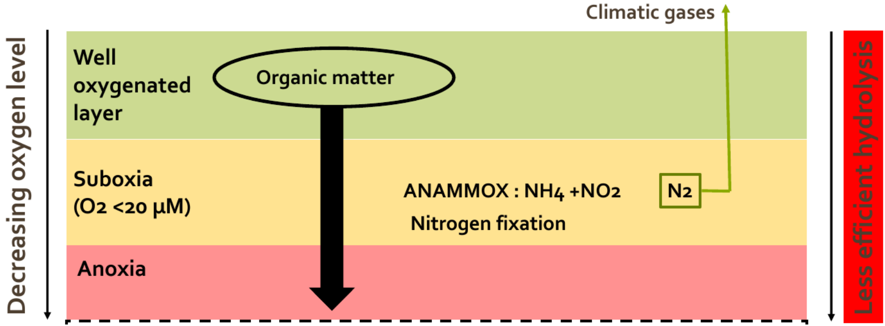

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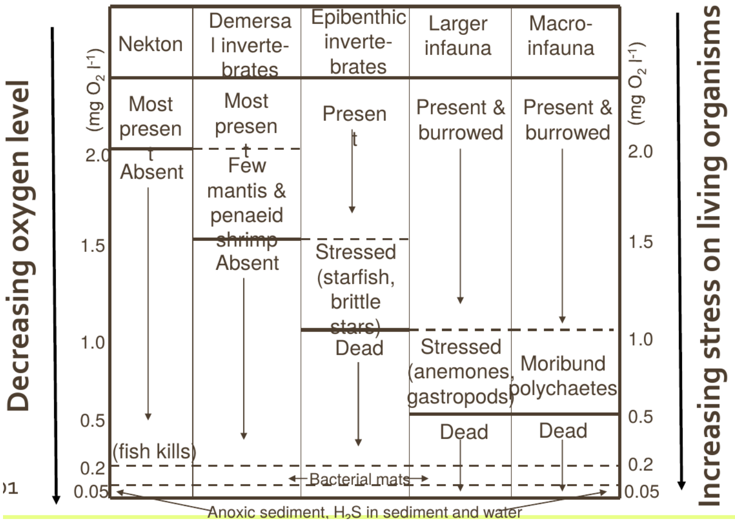

(Rabalais and Turner., 2001)

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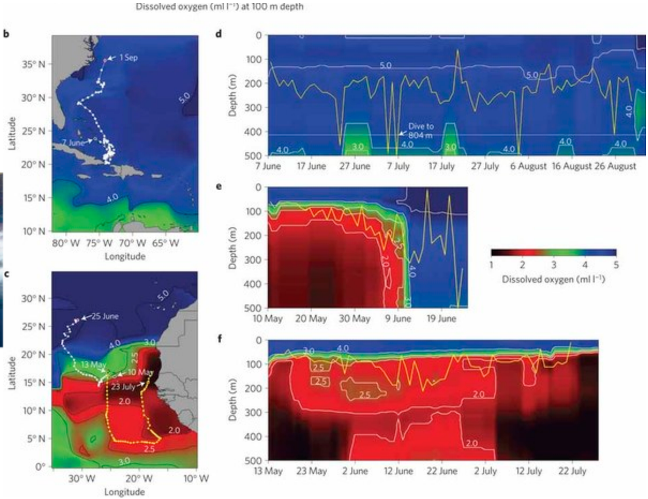


(Stramma et al., 2011)

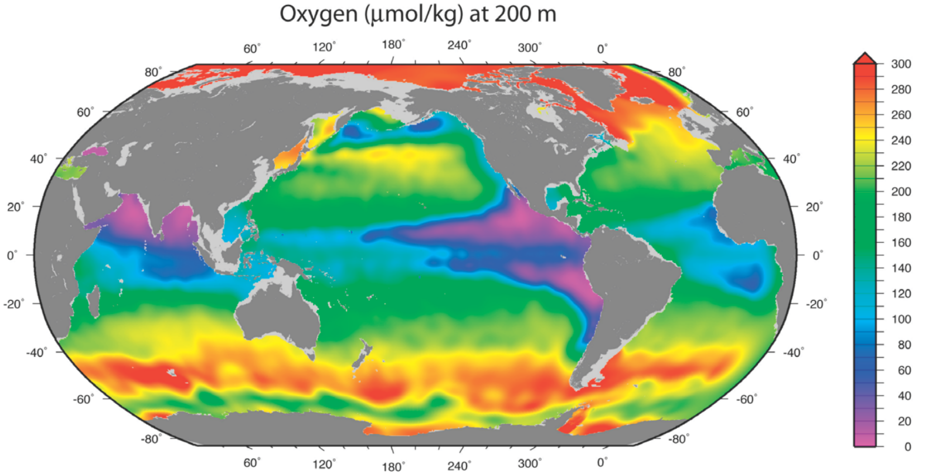
1 Why?

2 Different Morphologies

3 Modelling Challenges

4 The Black Sea case

Oxygen Minimum Zones in the Open Ocean



(Falkowski, 2011)

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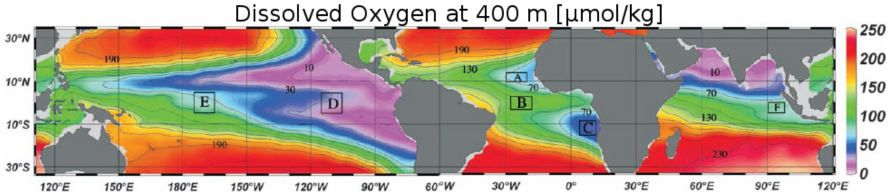

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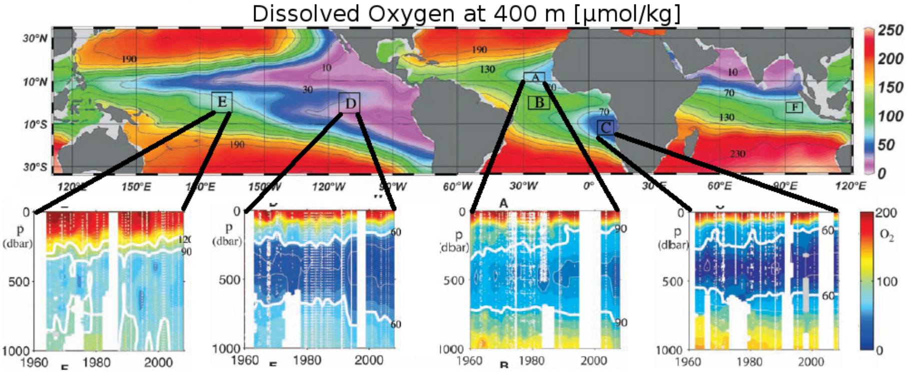

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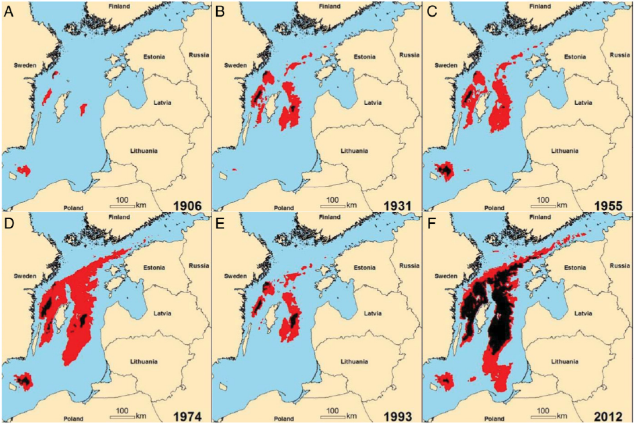
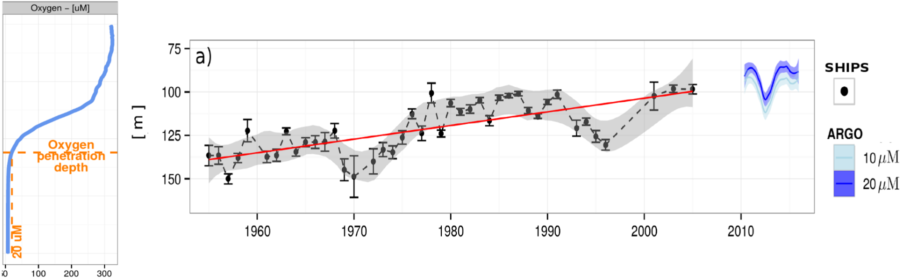
Oxygen Minimum Zones in permanently stratified basin



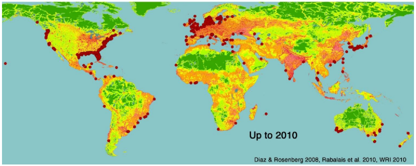
Baltic Sea, (Carstensen et al., 2014)

Oxygen Minimum Zones in permanently stratified basin

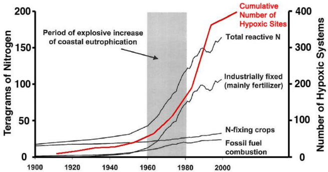


Black Sea, (Capet et al., 2016)

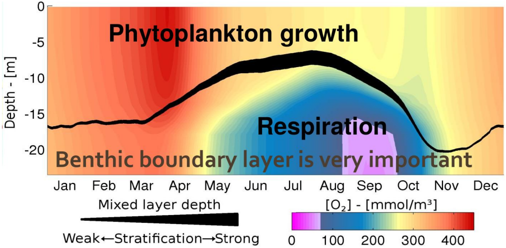
Oxygen Minimum Zones in coastal areas



Reported coastal dead zones
(Diaz & Rosenberg, 2008)



N loadings and coastal hypoxia increasing (redrawn from Boesch(2002), Diaz & Rosenberg, 2008, Breitburg(2015



(Capet et al, 2013)

- Seasonal or shorter stratification
- Sedimentation patterns
- Benthic-Pelagic coupling

Summary

- 7% of the global ocean total volume (Paulmier and Pino, 2009)
- natural occurence in some systems (e.g. high productivity, permanently stratified areas)
- The volume of OMZs is increasing (warming: stratification, decreased solubility, eutrophication)
- Pressure on Ecosystems : Habitat compression, mass mortality, affects benthos ecosystem functions
- Launch of the **Global Oxygen Network (GO2NE)** supported by IOC to integrate the various aspects of deoxygenation and to raise awareness

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United Nations
Educational, Scientific and
Cultural Organization

Intergovernmental
Oceanographic
Commission

Challenges for OMZ modelling

- Appropriately address the relevant processes.
- Valuate the impacts on ecosystem goods and services.

Key processes

- **General**: Suboxic Biogeochemistry
- **Coastal and shallow areas** Benthic-Pelagic Coupling
- **Open Ocean & EBUS** Meso- and Submeso- scales
- **permanently stratified basin** Diapycnal ventilation processes

Challenges for OMZ modelling

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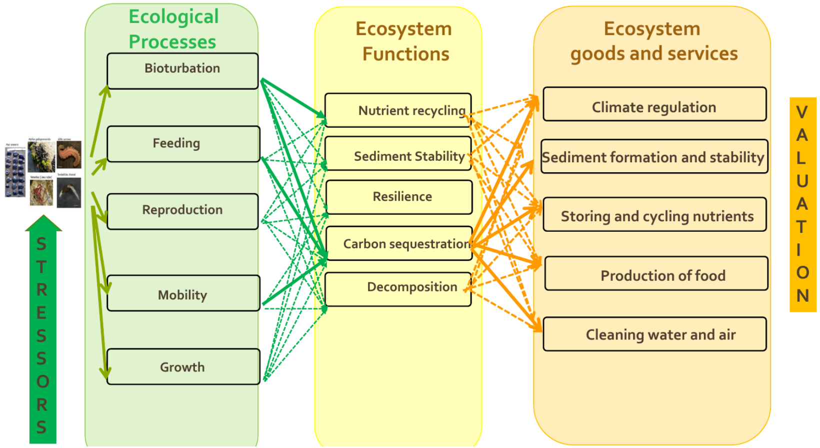

Challenges for OMZ modelling

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- Valuate the impacts on ecosystem goods and services.

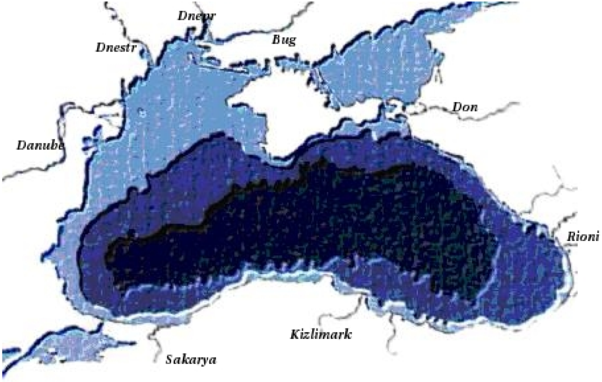
Connect Scales

Northwestern Shelf

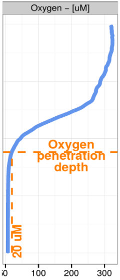
- Shallow
- Eutrophic
- Seasonal Hypoxia

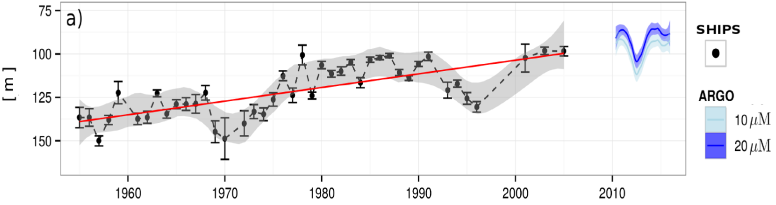
Open Sea

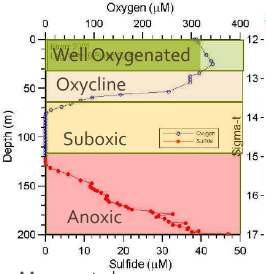
- Deep (2000 m)
- Stratified
- Permanent Anoxia

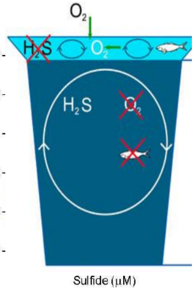


Shoaling oxycline in the central part



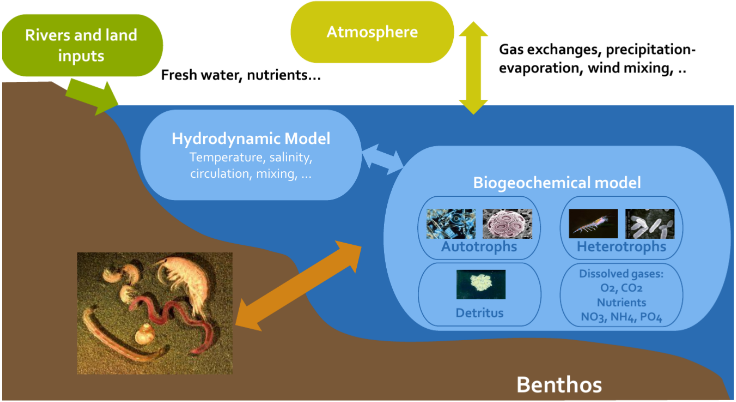






Murray et al., 2014

Seasonal hypoxia on the northwestern shelf



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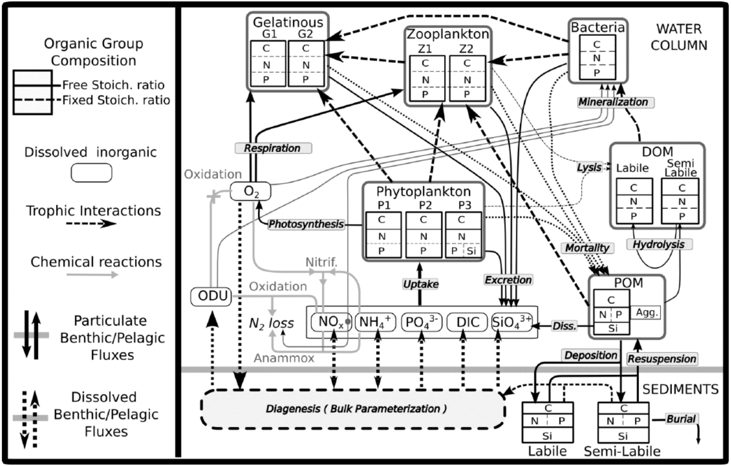

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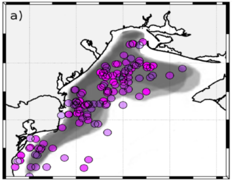
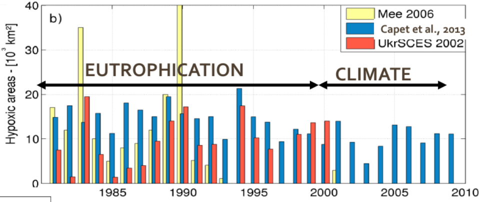
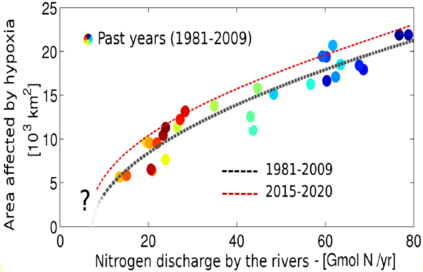
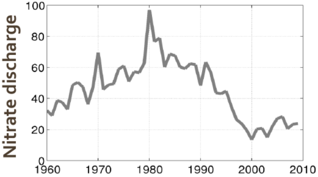
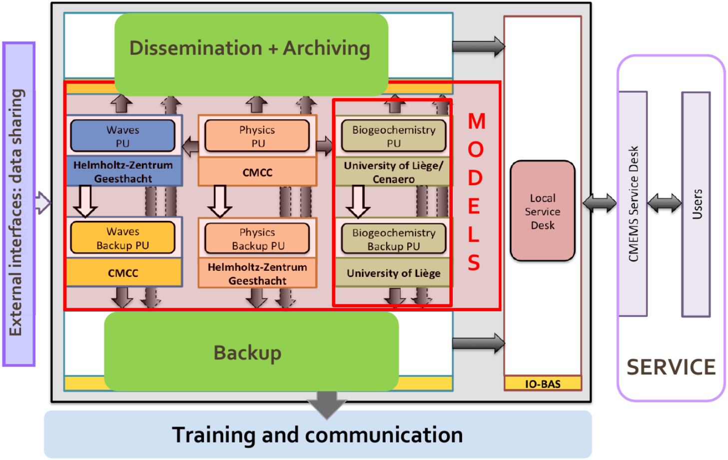


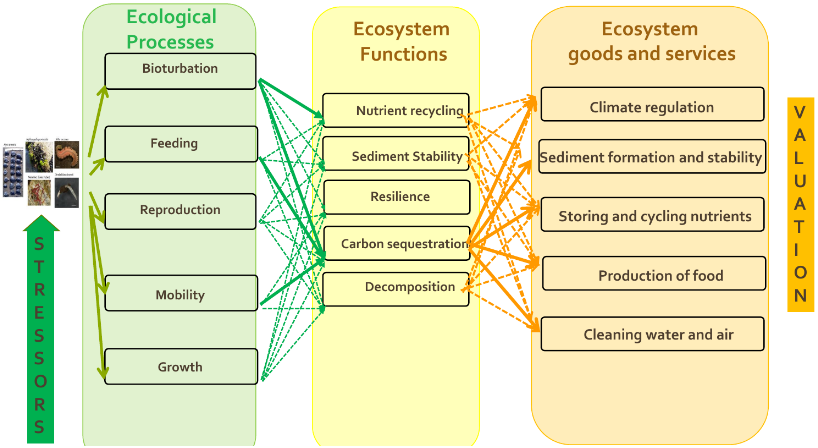






Black Sea Monitoring Forecasting Center

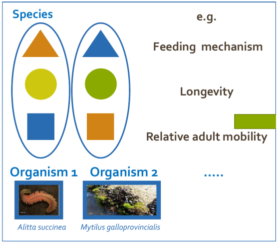



Ecological Processes
Bioturbation
Feeding
Reproduction
Mobility
Growth
Ecosystem Functions
Nutrient recycling
Sediment Stability
Resilience
Carbon sequestration
Decomposition
Ecosystem goods and services
Climate regulation
Sediment formation and stability
Storing and cycling nutrients
Production of food
Cleaning water and air
STRESSORS
VALUATION

Going further : A functional approach

Traits, (Violle et al., 2007 Oikos)

Morphological, physiological or phenological caracteristics defined at the level of the species



Biological Traits Species	Feeding mechanisms			Adult Longevity			Relative Adult Mobility			
	SF	DF	GB	<2	2-5	>5	None	Low	Medium	High
Mya arenaria	2	1	0	0	1	3	0	3	0	0
Mytilius galloprovincialis	3	0	0	0	1	3	3	1	0	0
Nereis rava	0	0	3	3	0	0	0	0	1	2
Terebellides stroemii	0	3	0	0	0	3	3	1	0	0
Lagis koreni	0	3	0	3	1	0	2	1	0	0
...										

Southwood hypothesis (1977)

The **habitat** provides the templet on which evolution forges characteristic life history **strategy**. This means that biological traits can be related to the physical and biogeochemical properties of the environment.

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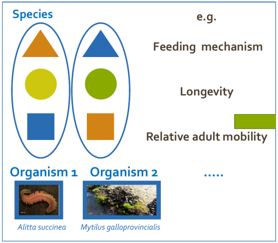

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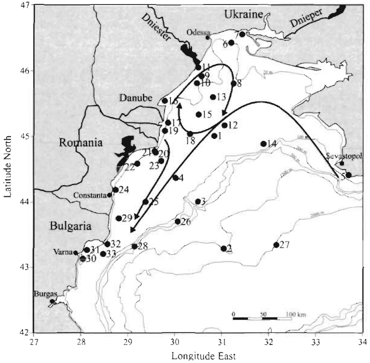
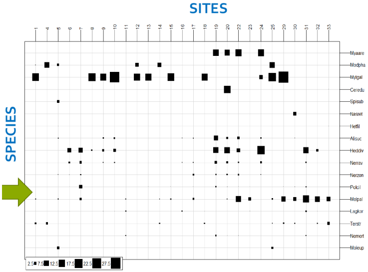
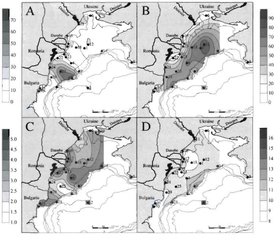
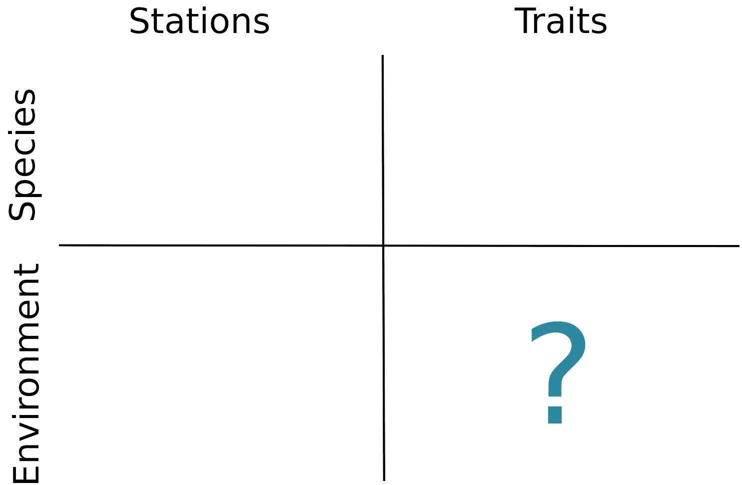
EROS21 dataset, August 1995, (Wijsman et al 1999)







RLQ analysis, (Legendre and Legendre, 2012; Dray et al., 2014)



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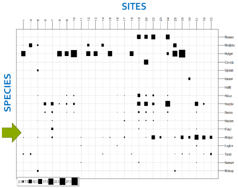
Stations

Traits

Species



Environment

?

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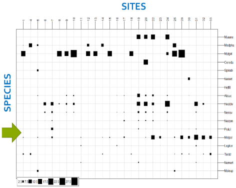

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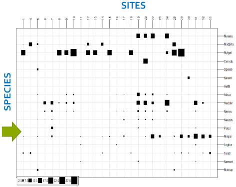

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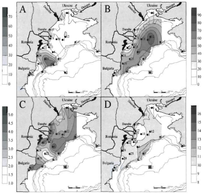

+ Model outputs

?

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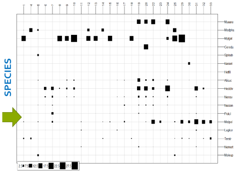
Stations

Traits

Species



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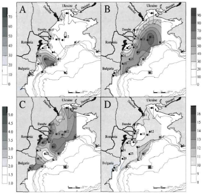
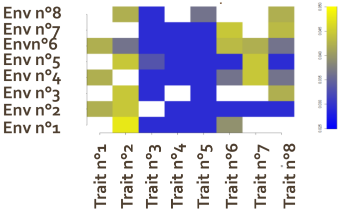
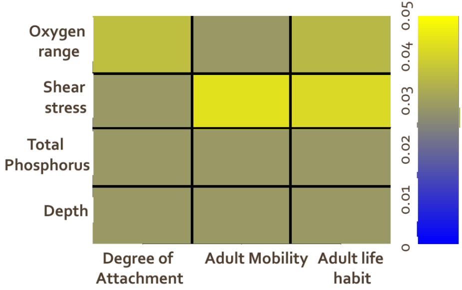


\+ Model outputs



Results for trait related to mobility

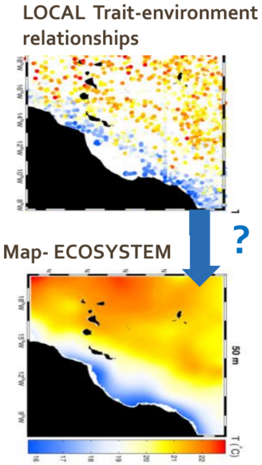


Significance (p-value) of the bivariate associations between traits and environmental variables (results from the fourth-corner tests). Significant associations correspond to p values <0.05

Significantly related environment variable

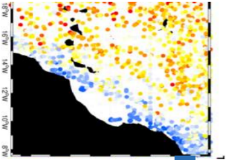
- Mean summer bottom shear stress
- Annual range of $[O_2]_{\mathrm{bottom}}$
- Total Phosphorus in the sediments
- Water Depth

Mapping of Ecological Traits



Mapping of Ecological Traits

LOCAL Trait-environment relationships



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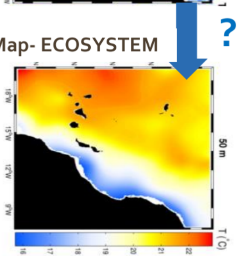
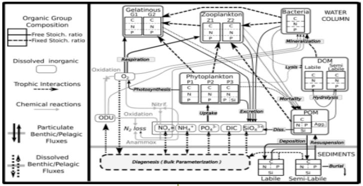
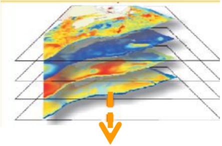
Map- ECOSYSTEM





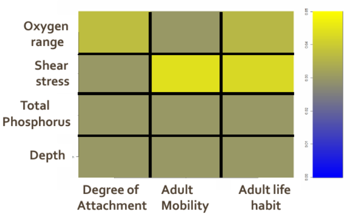
Temperature	Currents	Oxygen	Salinity	...



TRAITS MAPS

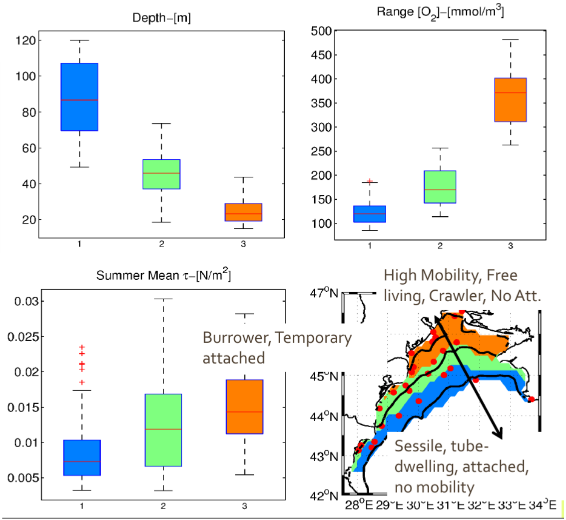
Mapping of Ecological Traits : Mobility

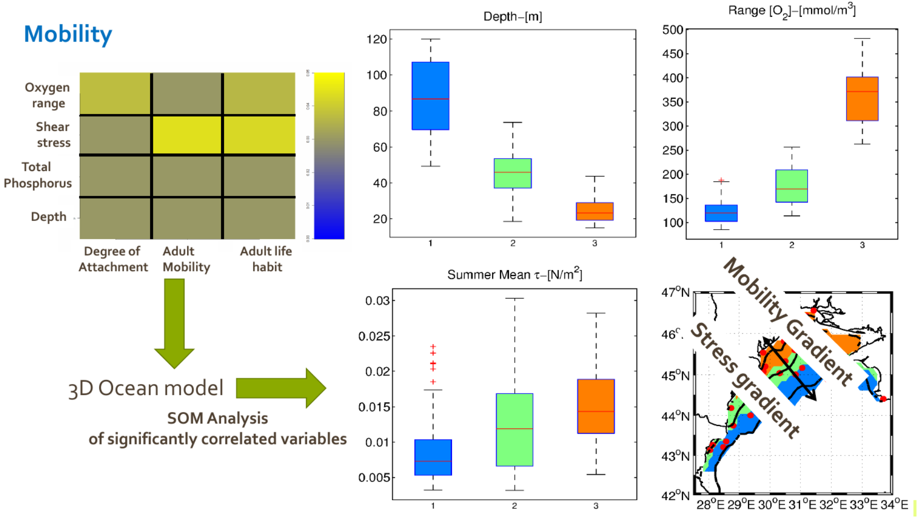
Mobility



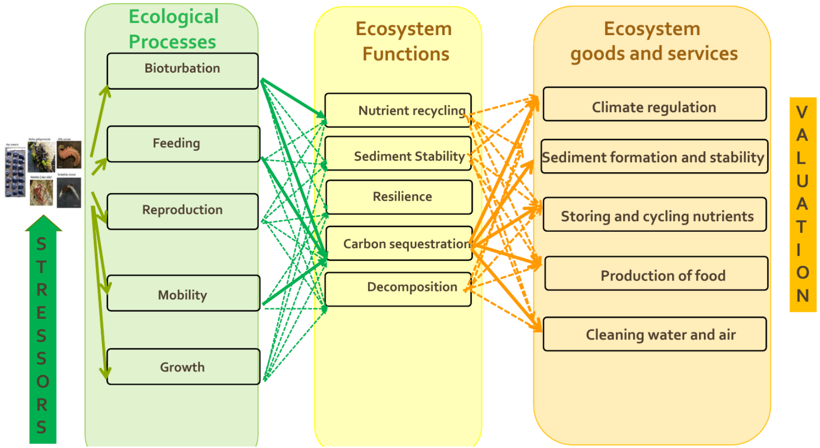
3D Ocean model

SOM Analysis of significantly correlated variables





Mobility
Oxygen range
Shear stress
Total Phosphorus
Depth
Degree of Attachment
Adult Mobility
Adult life habit
3D Ocean model
SOM Analysis
of significantly correlated variables
Depth–[m]
Range [O2]–[mmol/m3]
Summer Mean τ–[N/m2]
Mobility Gradient
Stress gradient
47°N
45°N
44°N
43°N
42°N
28°E 29°E 30°E 31°E 32°E 33°E 34°E



Ecological Processes
Bioturbation
Feeding
Reproduction
Mobility
Growth
Ecosystem Functions
Nutrient recycling
Sediment Stability
Resilience
Carbon sequestration
Decomposition
Ecosystem goods and services
Climate regulation
Sediment formation and stability
Storing and cycling nutrients
Production of food
Cleaning water and air
STRESSORS
VALUATION

From Traits to Ecological Processes

TRAIT	Modalities
Method of sediments reworking **(Reworking mode: Ri)**	(1) Epifauna that bioturbate at the sediment-water interface, (2) surficial modifiers (<1-2cm) (3) upward/downward conveyors that actively transport sediment to/from the sediment surface (4) biodiffusors
Propensity to move through the sedimentary matrix **(Mobility :Mi)**	(1) in a fixed tube (2) limited movement, sessile, but not in a tube (3) slow movement (4) free movement via burrow system

Increasing activity

Increasing impact on the sediment turnover

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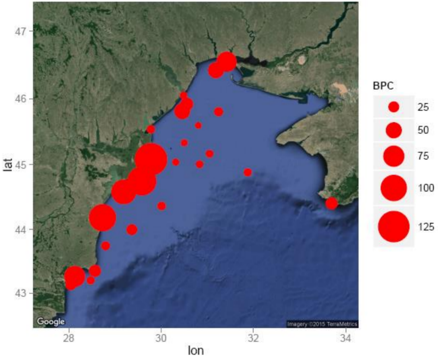

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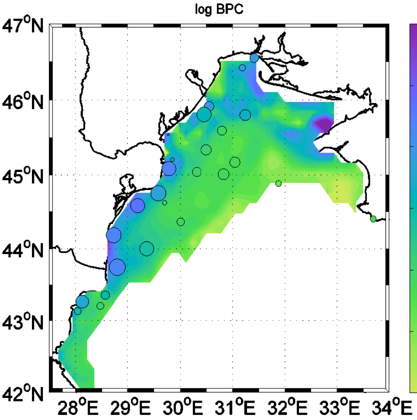
Community-level bioturbation potential

$$BPc = \sum_{i=species} \sqrt{B_i}.M_i.R_i$$

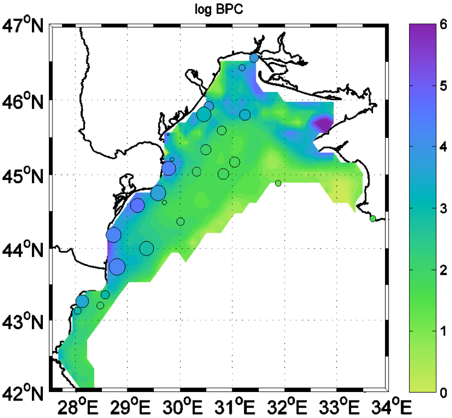
Multiple linear regression



$$log(BP_c) = f(OrgC, Hypoxiaindex, \tau, depth)$$
$$(R^2 = 0.77)$$

From Traits to Ecological Processes

Multiple linear regression



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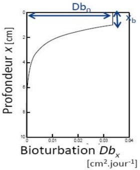
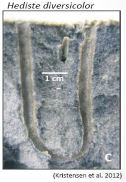
Variability of **biogenic mixing length**





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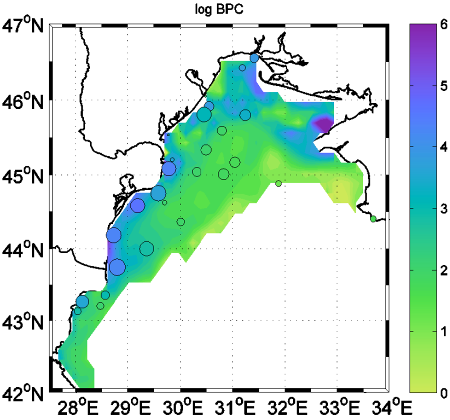

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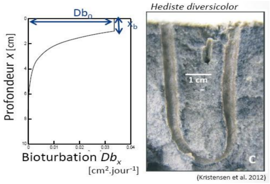
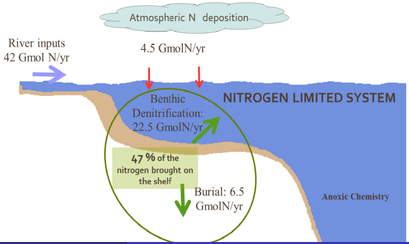
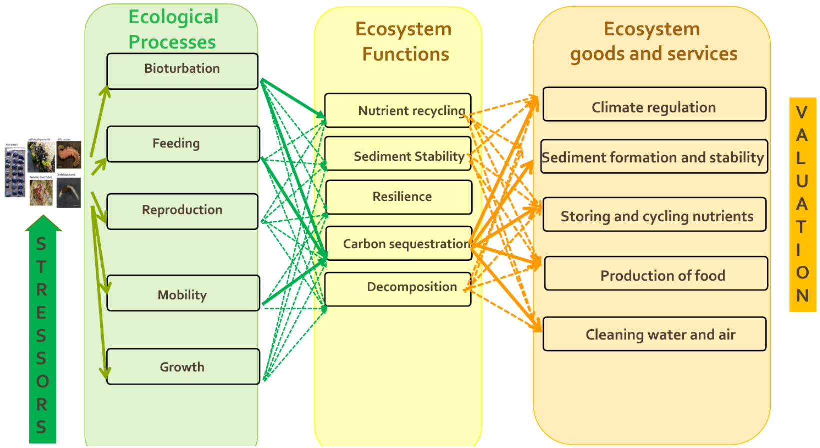


Inclusion in the model
→ revised shelf budgets

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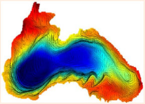
VALUATION

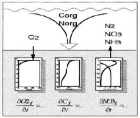
BENTHOX : Impact of low oxygen concentrations on Biogeochemistry and biodiversity

Field Experiments and laboratory analyses

Benthic Fluxes: Incubation, microprofiling
Macrobenthos: Van Veen grabs
Diagenesis: Porewater profiles, solid phase
Sediment cores analyses: reconstructing the past

Model development and simulations

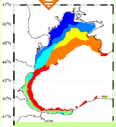




Scenarios Management recommendations

Methodology and diagnostics definition for assessing the Good Environmental Status of marine waters.

Projections at the horizon 2020 and 2050



Habitat modeling

BenthOx

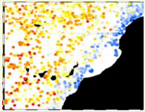
fnrs LA LIBERTÉ DE CHERCHER

(2016-2020)

Summary

LOCAL

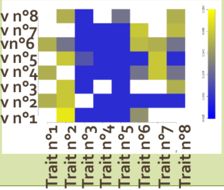
DATA



TRAITS

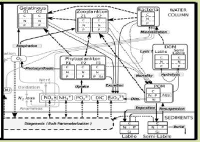
Biological Traits Species	Feeding mechanisms			Adult Longevity		
	SF	DF	GB	<2	2-5	>5
Mya arenaria	2	1	0	0	1	3
Mytilus galloprovincialis	3	0	0	0	1	3
Nereis rava	0	0	3	3	0	0
Terebellides stroemii	0	3	0	0	0	3
Lagis koreni	0	3	0	3	1	0
...						

RLQ

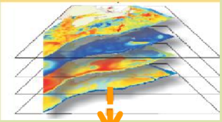


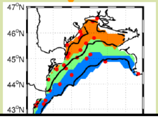
ECOSYSTEM SCALE

OCEAN MODEL



MAPS





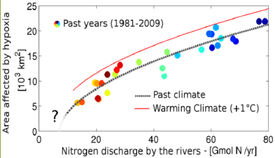
FUNCTIONAL BIOGEOGRAPHIC MODEL

ECOSYSTEM SERVICE

Impact of the functions of the benthos on ecosystem services

& impact of environmental changes on this service

e.g. **HYPOXIA**



Thanks for your attention ...
... and questions

More info on :

- Seasonal hypoxia on the northwestern shelf:
  Capet et al, 2013, *Biogeosciences*
- Benthic-Pelagic coupling in the model:
  Capet et al, 2016, *Ocean Modelling*
- Decline of the Black Sea oxygen inventory:
  Capet et al, 2016, *Biogeosciences*