United Nations
Educational, Scientific and
Cultural Organization

Intergovernmental
Oceanographic
Commission

Organisation
des Nations Unies
pour l'éducation
la science et la culture

Commission
océanographique
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Comisión
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Организация
Объединенных Наций по
вопросам образования
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Межправительственная
океанографическая
комиссия

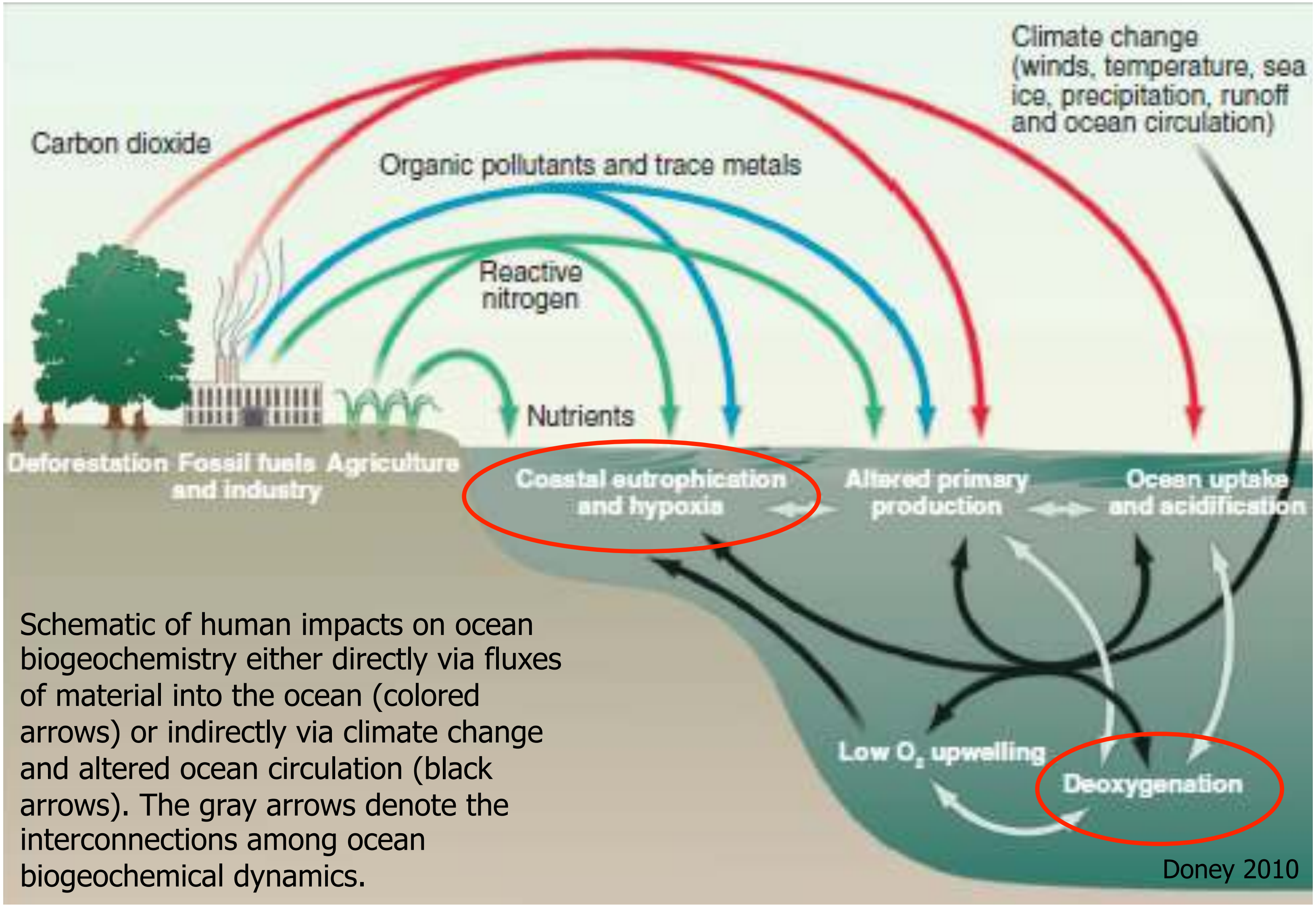
The Ocean is Losing its Breath

Kirsten Isensee

Intergovernmental Oceanographic Commission of UNESCO

Brest, 18 May 2015

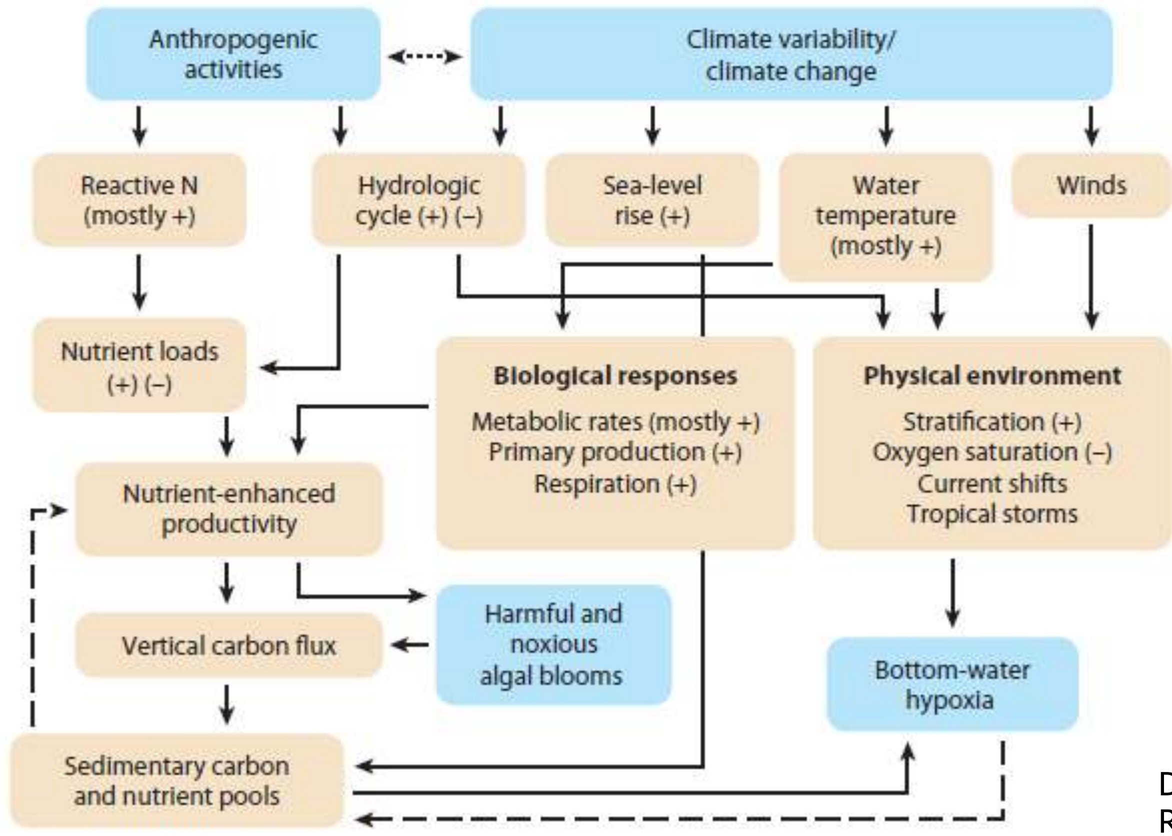
Deoxygenation of coastal and oceanic waters



Schematic of human impacts on ocean biogeochemistry either directly via fluxes of material into the ocean (colored arrows) or indirectly via climate change and altered ocean circulation (black arrows). The gray arrows denote the interconnections among ocean biogeochemical dynamics.

Doney 2010

Deoxygenation of coastal and oceanic waters



Doney et al. 2010,
Rabalais et al. 2009

Potential physical and hydrological changes resulting from climate change and their interaction with current and future human activities. The dashed lines represent negative feedback to the system.

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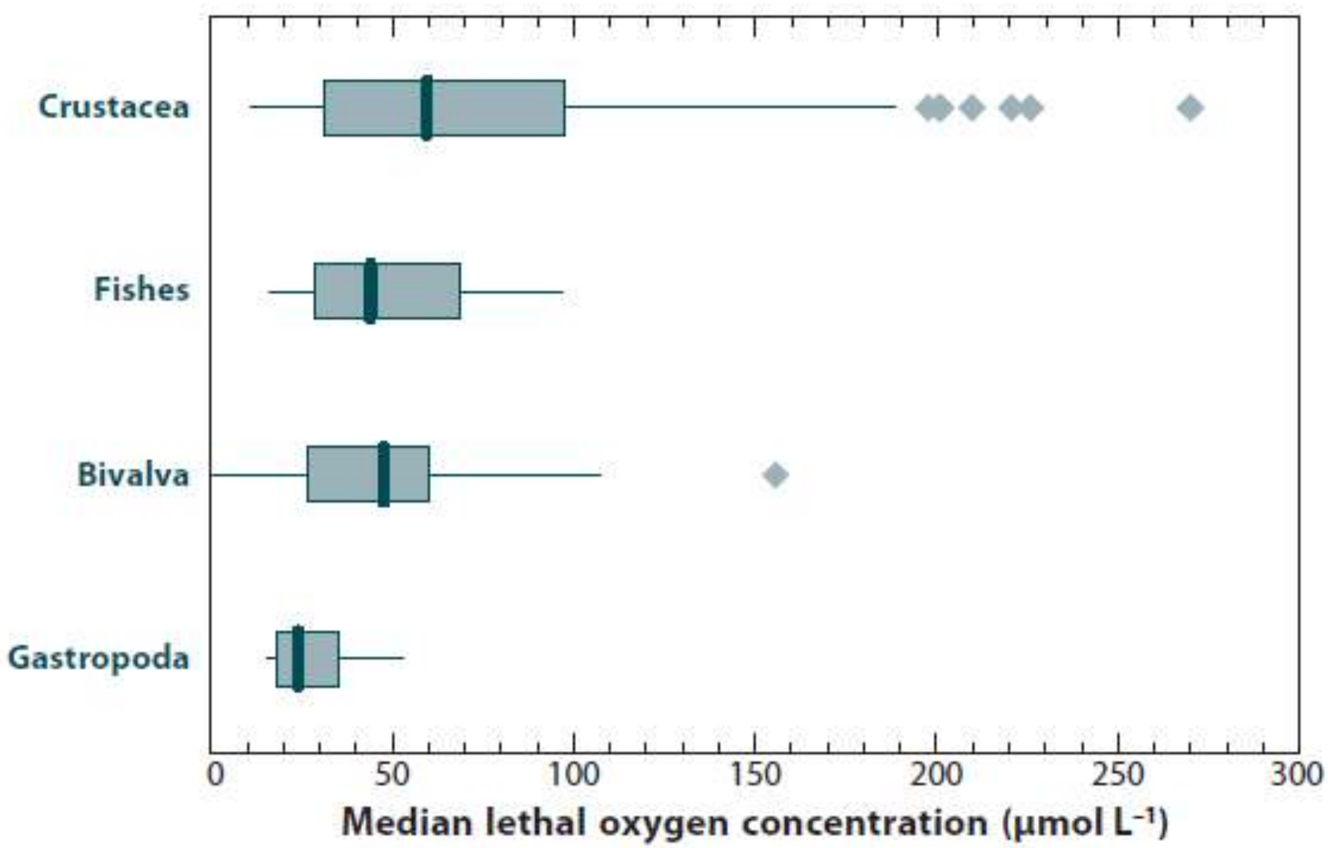
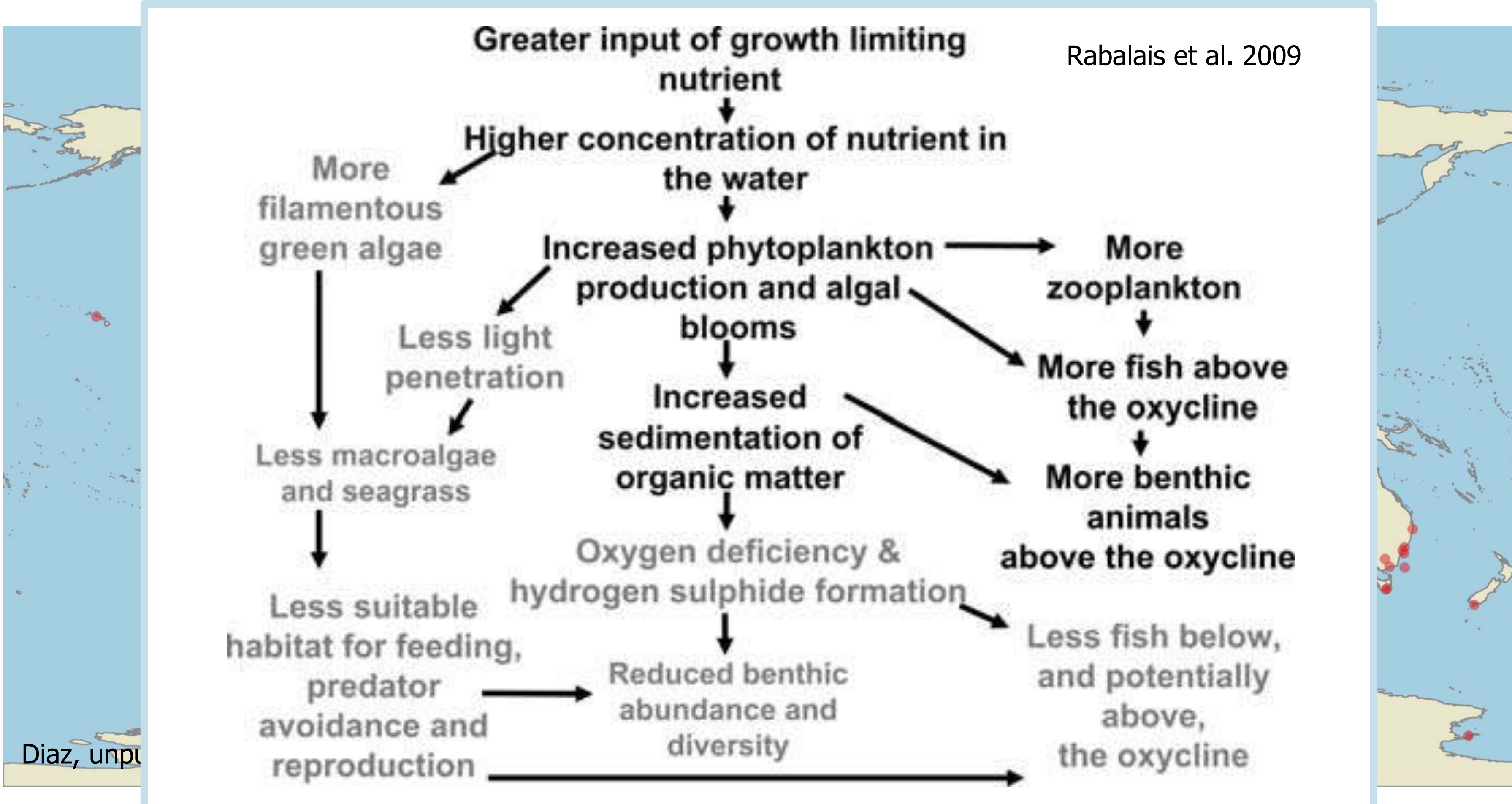
Taxa depending impact of deoxygenation



Keeling et al. 2010

Deoxygenation of coastal waters – Dead Zones



Schematic representation of the cascading effects of increasing nutrients in a coastal ecosystem. The harmful effects of nutrient over-enrichment are presented in grey letters.

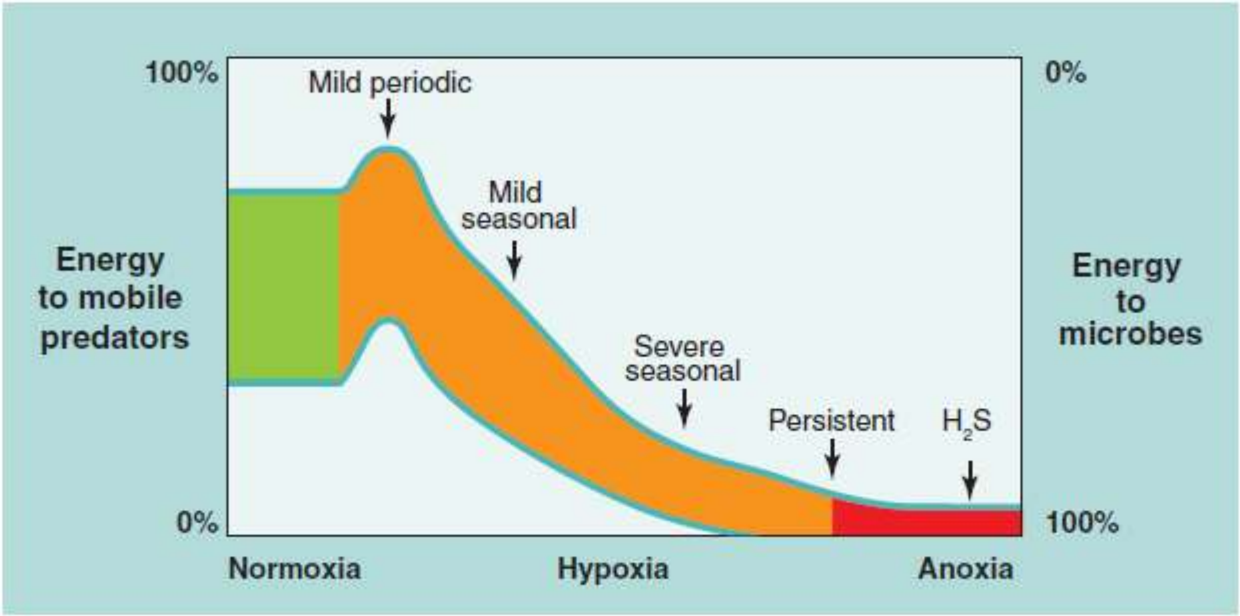
Deoxygenation of coastal waters – Dead Zones

Hypoxia impacts biogeochemical cycling and may significantly disturb ecosystem functionality:

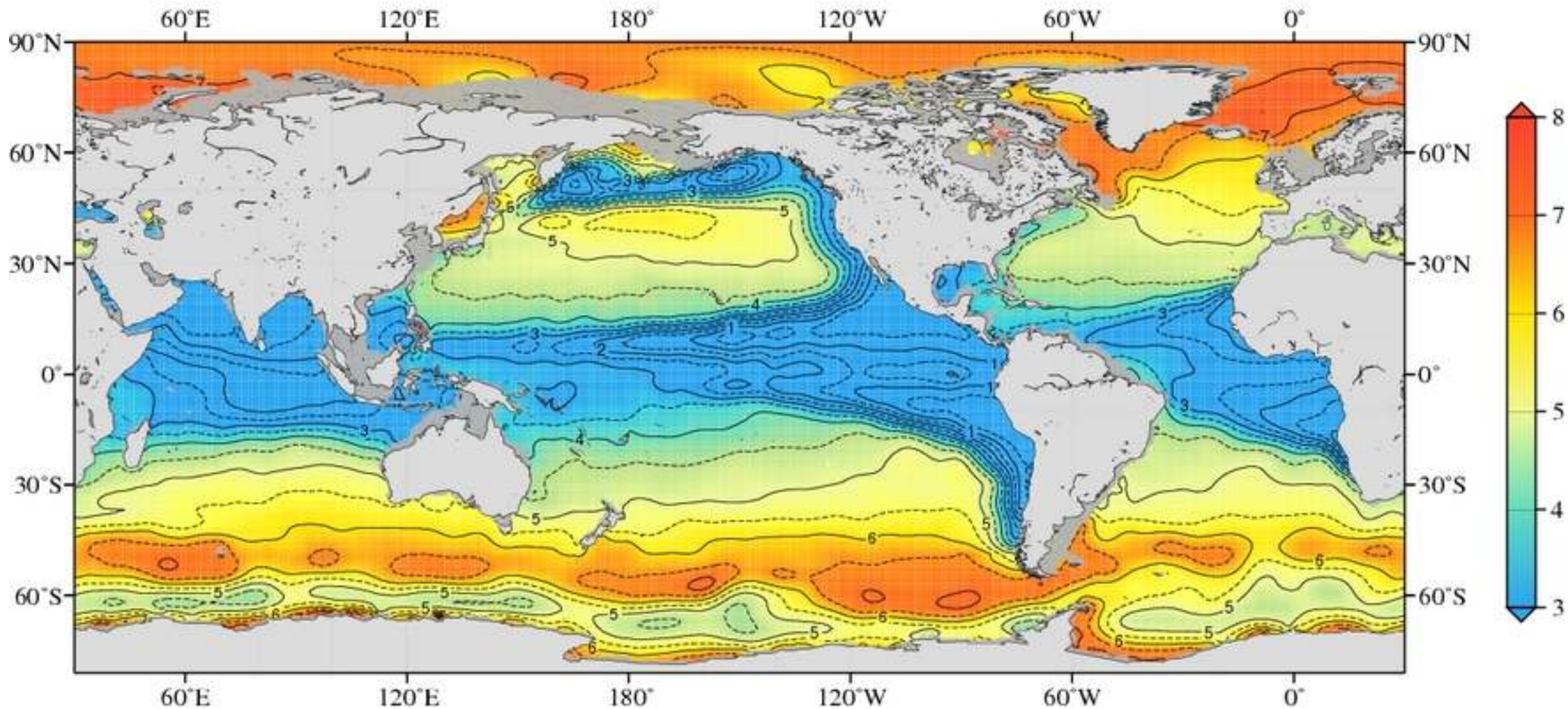
- directly affects living organisms (e.g., benthic organisms, fishes),
- may, in extreme cases, lead to anoxia with the production of greenhouse gases (e.g., CH_4, N_2O), or toxic substances (e.g., sulfide),
- alters the cycling of chemical elements such as nitrogen or phosphate,
- modifies the sedimentary geochemical cycling through the removal of bioturbating infauna,
- alters the food web structure by changing the balance of chemical elements (e.g., N, C, P) and by killing some components and hence reducing the transfer of energy towards the higher trophic levels.

Impact of Hypoxia on ecosystem energy flow

Diaz & Rosenberg 2008

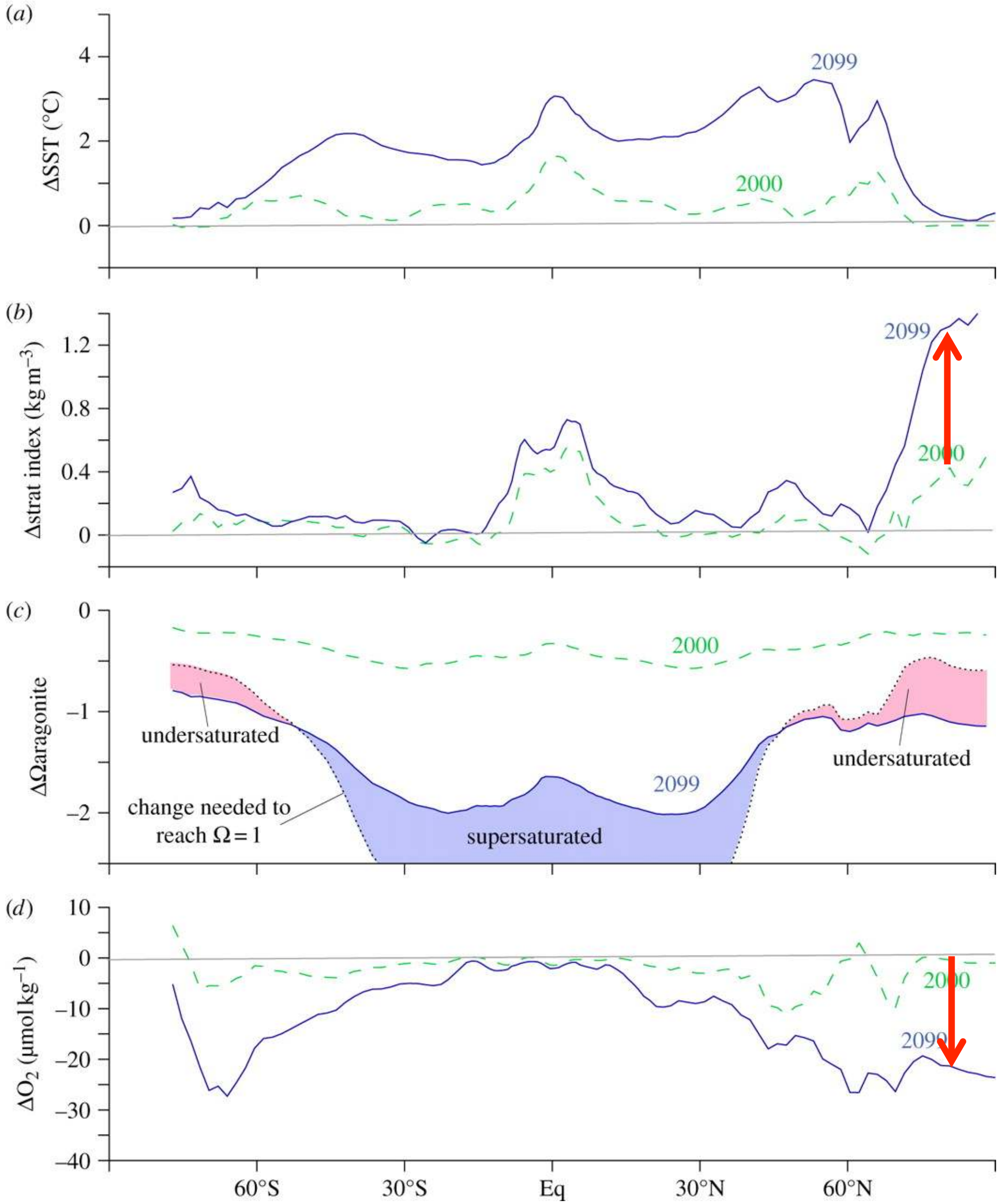


Deoxygenation of oceanic waters – Oxygen Minimum Zones



Annual oxygen [ml/l] at 200 m. depth (one-degree grid)

World Ocean Atlas 2013, Garcia et al. 2014



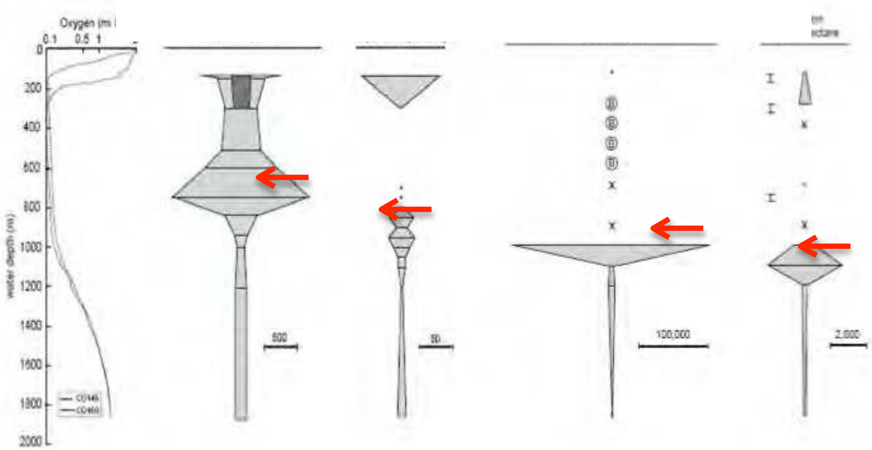
Gruber 2011

Zonal mean profiles of model-simulated changes in ocean properties for 2099 (under the IPCC SRES A2 scenario) and 2000 relative to the year 1850 (atmospheric CO_2 – 1850: 280 ppm; 2000: 370 ppm; 2099: 840 ppm).

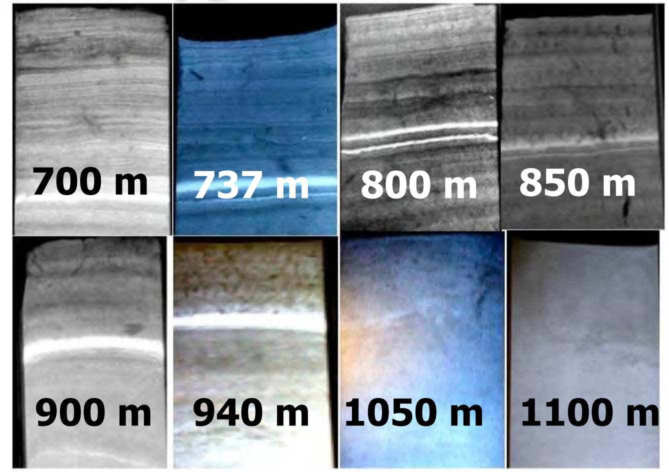
a) Change in sea-surface temperature;
b) change in upper ocean stratification, density gradient between 0–50 m and 100–200 m;
c) change in the surface aragonite ocean saturation state;
d) change in the mean concentration of oxygen in the thermocline (200–600 m).

Results are from the NCAR CSM 1.4 model.

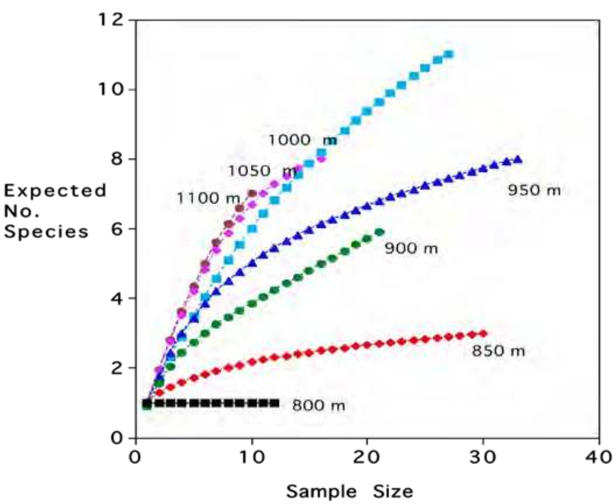
Multiple consequences of low oxygen in OMZs



Altered Size Structure and Composition

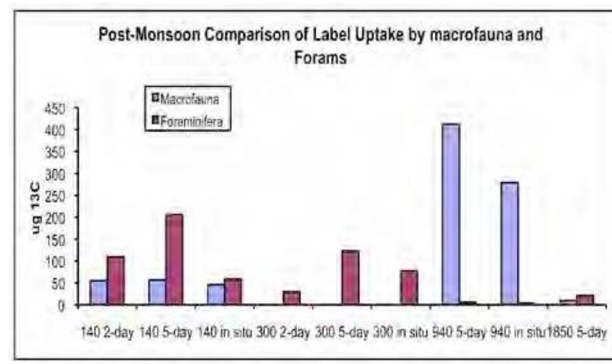


Reduced Bioturbation



Rapid Biodiversity Shifts

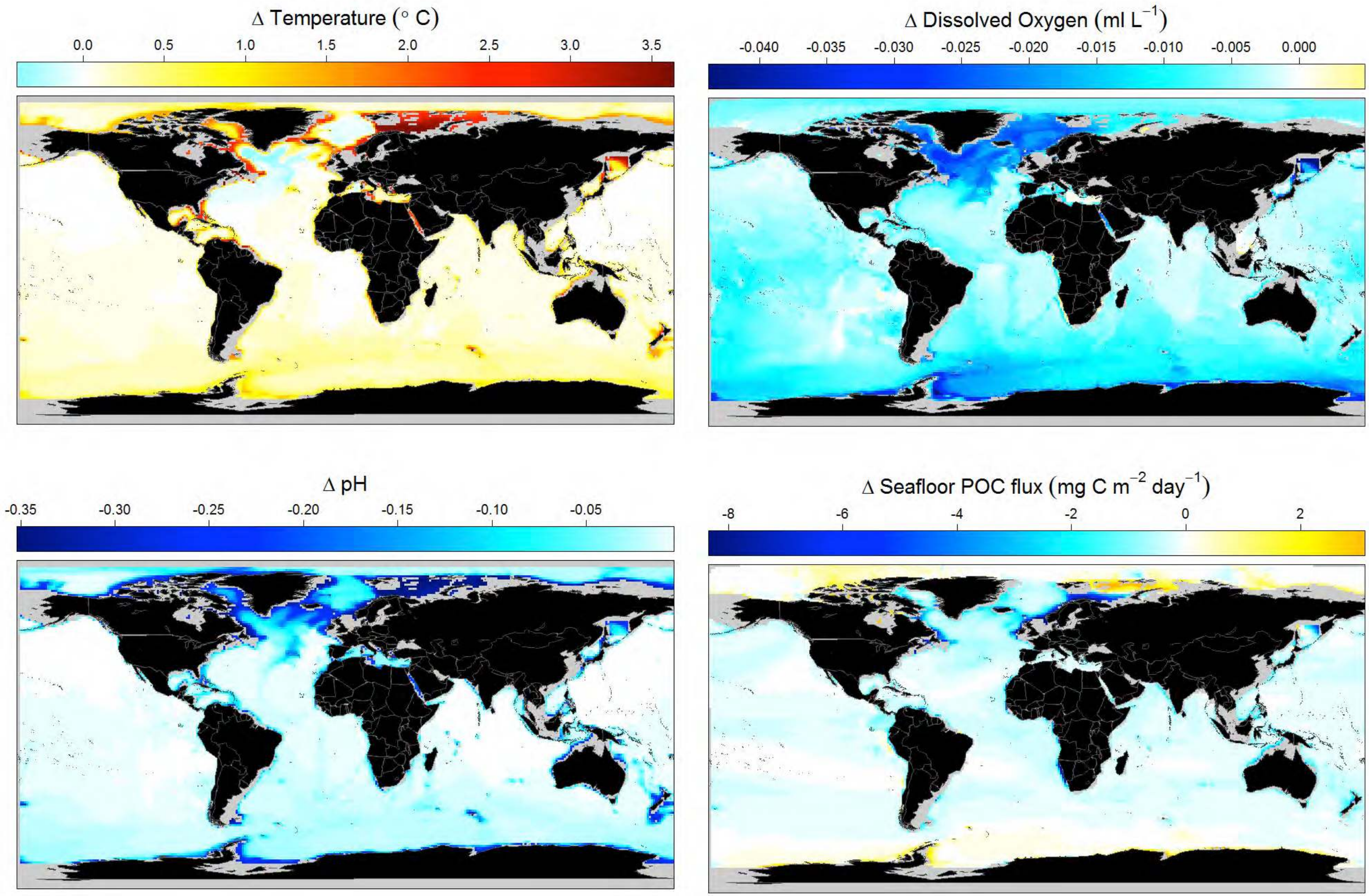
Reduced Colonization



Altered Carbon Processing

Would et al. 2007; Levin et al. 2009; Gooday et al. 2009; Levin et al. 2013

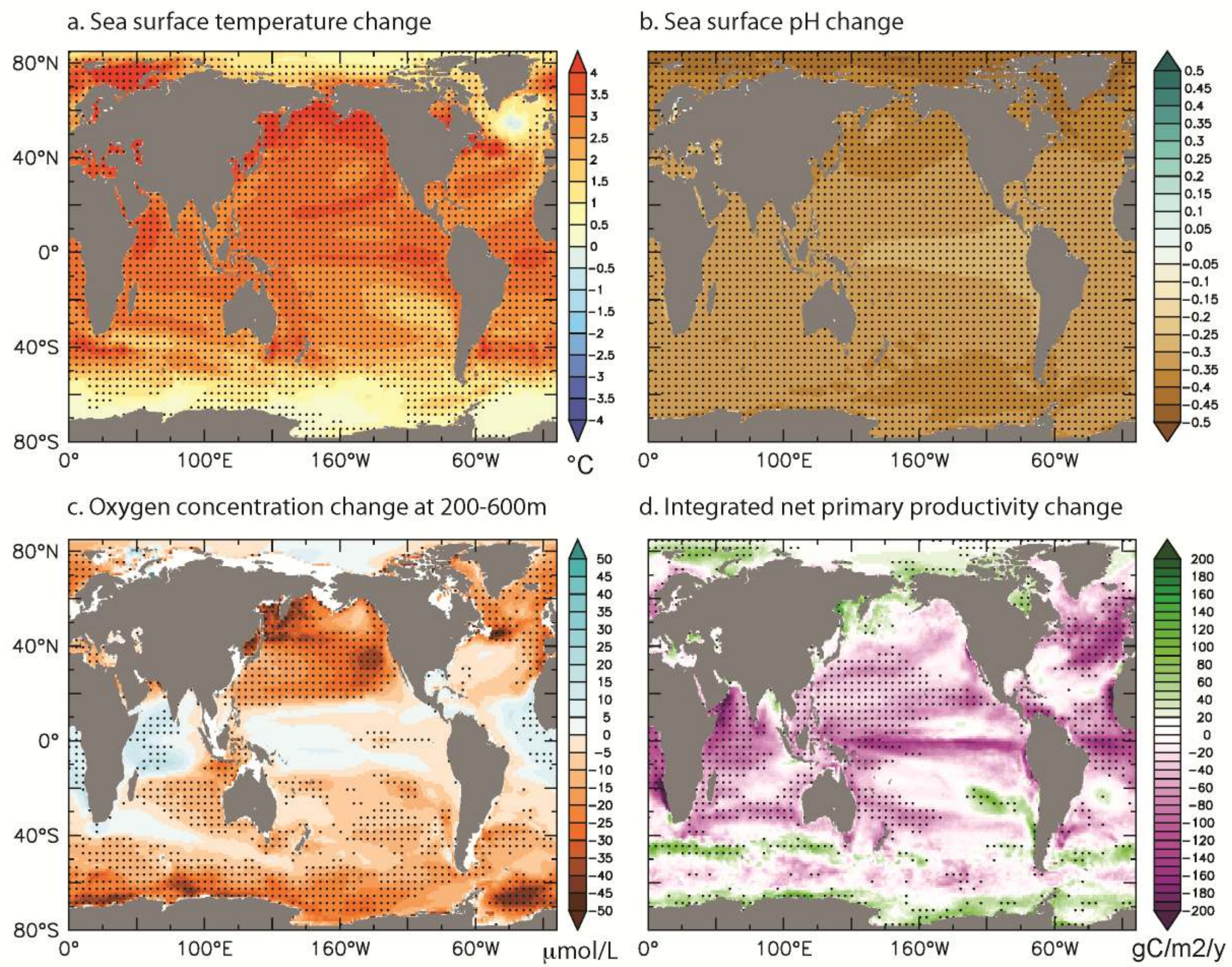
Projections of oceanic waters – Bottom Waters



Mora et al. 2013

Projected Change on the Deep-Sea Floor - 2100

Projections of oceanic waters – Surface Waters



Projected changes in sea surface temperature, pH, dissolved oxygen concentration and primary production in 2090-2099 relative to 1990-1999 under the RCP8.5 'business as usual' scenario.

Bopp et al., 2013; figure courtesy of L. Bopp

Consequences of Hypoxia

Declining oxygen affects virtually all biogeochemical and biological marine processes

Direct effects on aerobic organisms

- Negative impact on growth, reproduction survival

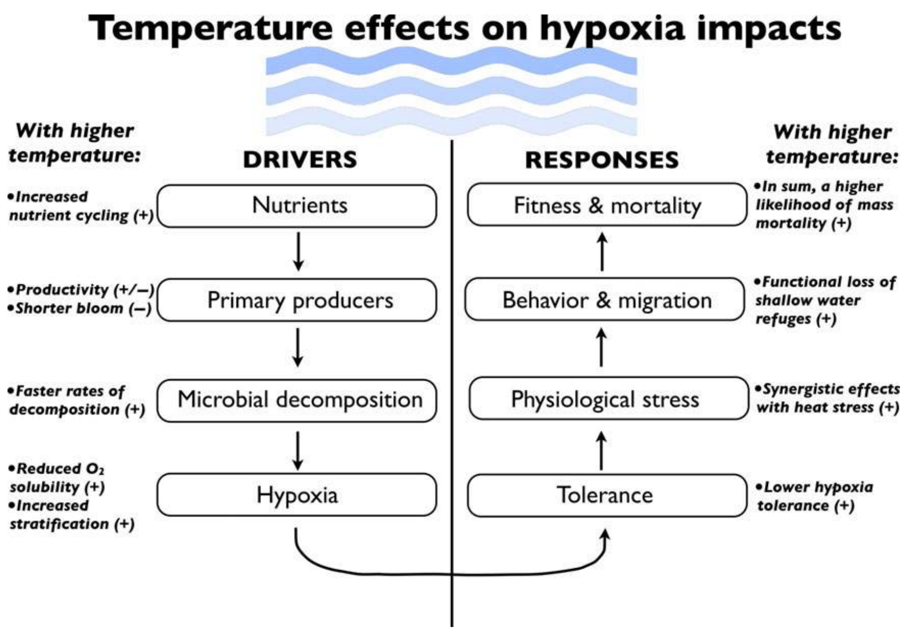
Indirect through altered ecological interactions

- Negative impact on functional attributes of communities, e.g. biodiversity, resilience, food-web structure

Loss of ecological services, human depend on –

in particular food security, tourism and conservation, but also shoreline protections, nutrient cycling , carbon sequestration

Multiple Stressor Challenge

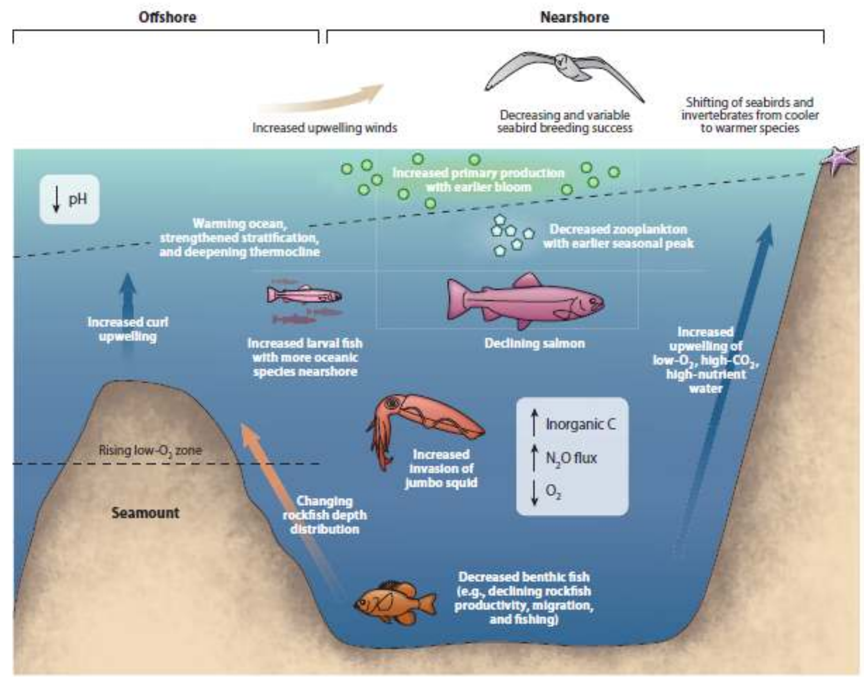


Altieri & Gedan 2014

Summary of climate-dependent changes in the California Current.

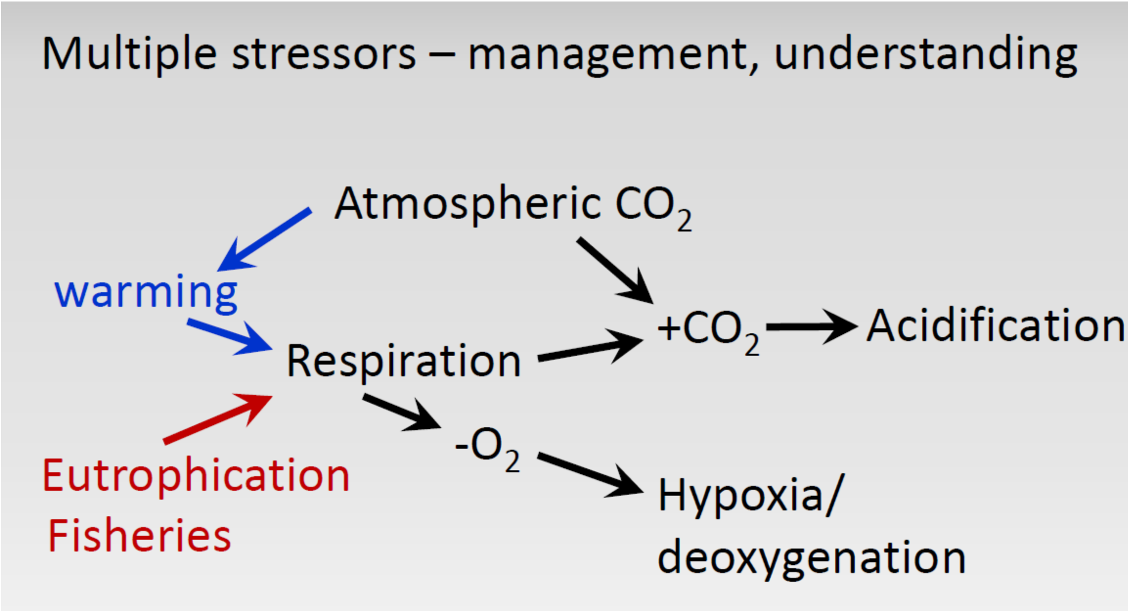
Observed physical changes include:

surface warming, strengthened stratification, a deepening thermocline that is superimposed on strengthened upwelling wind stress, resulting in increased coastal and curl-driven upwelling.



Doney et al. 2012

Multiple Stressor Challenge



- For mobile species, hypoxia can determine exposure to acidification
- Almost all species tested behaviorally avoid low dissolved oxygen.
- Co-occurring hypoxia and acidification may reduce exposure to respiration-driven acidification.
- Individual stressors can either exacerbate or reduce effects of other stressors.
- **We can't predict consequences or manage effectively if we don't consider the full context in which organisms live**

Moving forward:

CURRENT STATE

- Much of the information we have is based on activities from North America, Europe and Asia

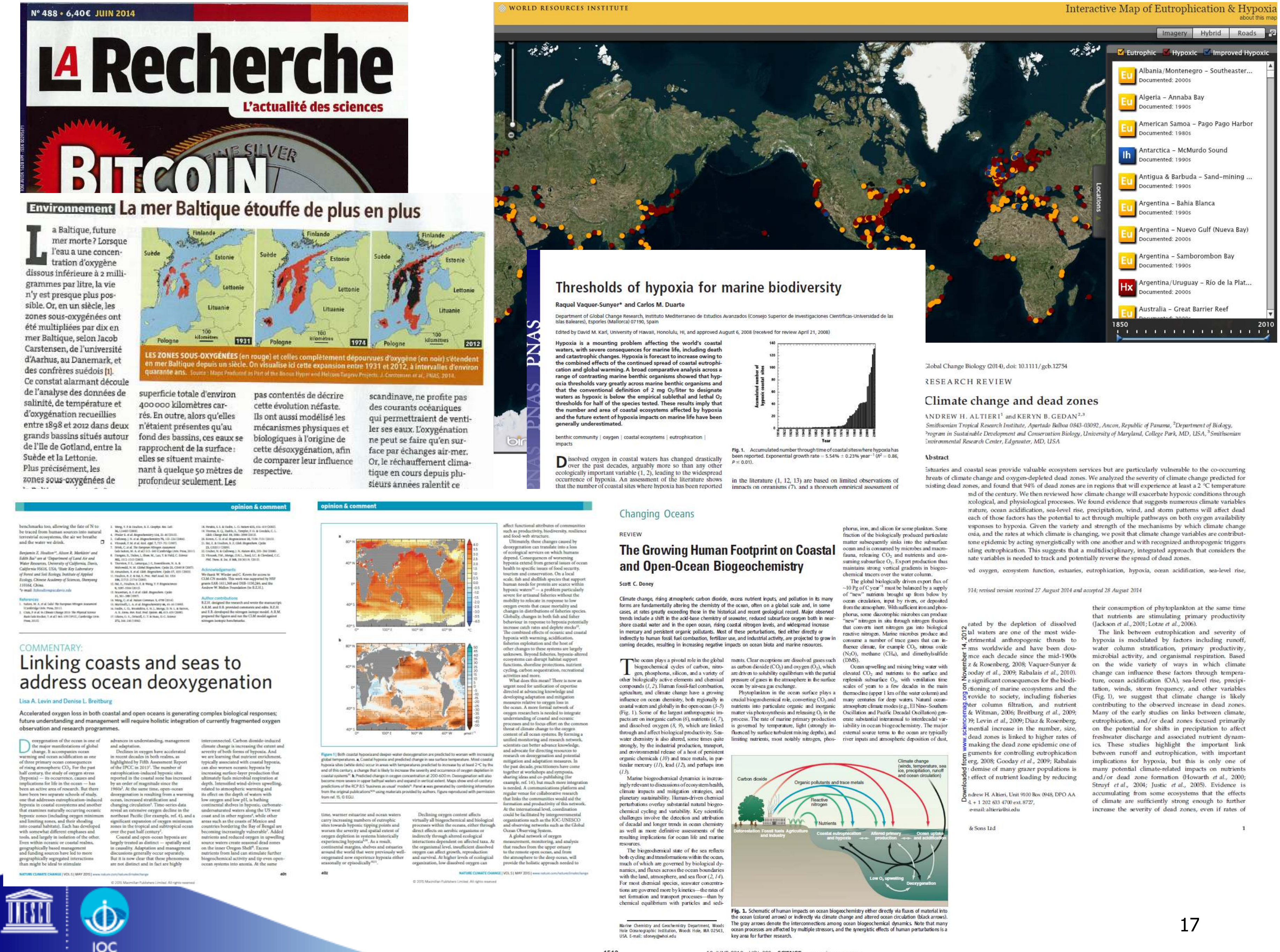
  → **Missing a lot of upwelling regions**

- **Developing countries face severe hypoxia**, e.g. Pearl River in China, similar in the past also in Europe (Thames) and US (Delaware River)
- We **know little** about oceanographic conditions in the **least populated areas in the world**
- **Scarce information on monetary assessment** accounting for the impact of deoxygenation
- **Model simulations still have difficulties** in properly representing oxygen historical data (Cabré et al. 2015)
- **Lack a full understanding of mechanisms controlling** oxygen in the ocean interior and on the shelves
- Nevertheless models predict **continued and intensified ocean deoxygenation**
- **Separate schools** of oxygen researchers **open ocean vs. coastal/estuarine**

Moving forward:

FUTURE CHALLENGES

- Future scenarios for oxygen depend on a combination of drivers related to global environmental change and land-use, including warming, growing human population, and extensive coastal agricultural practices
- Need for integrated action – Formal Coastal and Open Ocean OXYGEN Researchers network
- New collaborative research:
    - Identify knowledge gaps
    - Expand global coverage
    - Revise model calculations
    - Standardize applied methods
    - Improve predictions for food security and tourism
    - Evaluate impact on non-market ecosystem services
    - Value the impact of ocean deoxygenation
- Better advocate for directing resources to research on deoxygenation and potential mitigation and adaptation measures


N° 488 • 6,40€ JUIN 2014
La Recherche
L'actualité des sciences
Bitcoin
Environnement La mer Baltique étouffe de plus en plus
LES ZONES SOUS-OXYGÉNÉES (en rouge) et celles complètement dépourvues d'oxygène (en noir) s'étendent en mer Baltique depuis un siècle. On visualise ici cette expansion entre 1931 et 2012, à intervalles d'environ quarante ans.
WORLD RESOURCES INSTITUTE
Interactive Map of Eutrophication & Hypoxia
PNAS
Thresholds of hypoxia for marine biodiversity
Raquel Vaquer-Sunyer and Carlos M. Duarte
Global Change Biology (2014), doi: 10.1111/gcb.12754
RESEARCH REVIEW
Climate change and dead zones
ANDREW H. ALTIERI and KERYN B. GEDAN
opinion & comment
COMMENTARY:
Linking coasts and seas to address ocean deoxygenation
Lisa A. Levin and Denise L. Breitburg
Changing Oceans
REVIEW
The Growing Human Footprint on Coastal and Open-Ocean Biogeochemistry
Scott C. Doney
18 JUNE 2010 VOL 328 SCIENCE www.sciencemag.org

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Thank you!

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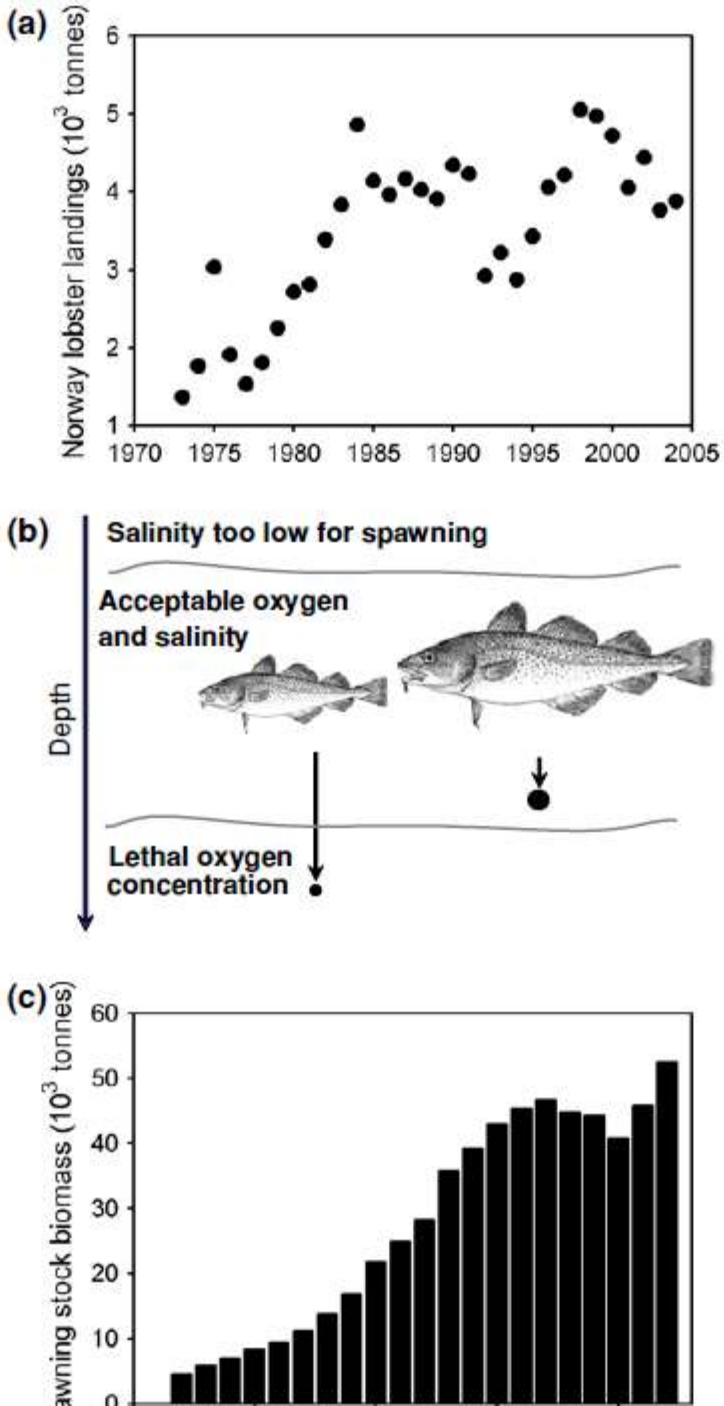
Lisa Levin, Denise Breitburg, Veronique Garçon, Marilaure Gregoire, Luis Valdés



◄**Fig. 4** Strong interactions between fisheries mortality and eutrophication occur because of effects of eutrophication on behaviors, effects of fisheries removals on population size structure, and because of the magnitude of mortality caused by fisheries exploitation. **a** Behavior: Norway lobster. Behavioral responses to hypoxia can increase the susceptibility of organisms to fishing gear, and at least initially result in increased landings. Catch per unit effort of Norway lobsters in the Kattegat along the coast of Sweden peaked in the mid-1980s, as worsening hypoxia induced lobsters to leave their burrows, making them more accessible to nets (Baden et al., 1990). Nevertheless, landings of Norway lobster in the Kattegat–Skagerrak area have remained high. **b** Size distributions: Baltic cod. Fisheries regulations can indirectly influence the susceptibility of cod eggs to hypoxia-induced mortality by influencing the size of spawning females in the population. Large females produce large eggs that are sufficiently buoyant to be retained in oxygenated mid-depth waters; smaller females produce small eggs that sink and perish (Vallin & Nissling, 2000). Cod image http://stellwagen.noaa.gov/visit/welcome.html. **c** Reduced fishing mortality: Striped bass. Decisive management action taken to protect spawning stock biomass of striped bass in Chesapeake Bay is often cited as a successful example of fisheries management. Stringent fishing regulations allowed the population to rebound even though eutrophication and its potential to negatively affect striped bass growth and habitat persisted

and adults from hypoxia (i.e., fish kills), and other consequences of eutrophication (e.g., harmful algal blooms; HABs) is typically a relatively small proportion of total mortality. The primary effect of fishing is the removal of biomass, often of late juveniles or adults that have high reproductive value, and shifts in size structure to smaller body size. These effects may drive strong declines in abundance and, if they exceed the compensatory reserve of the population, decreases in population growth rates. In contrast, eutrophication can result in both increases and decreases in growth