



United Nations Educational, Scientific and Cultural Organization

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

Organización de las Naciones Unidas para la Educación la Ciencia y la Cultura

Организация Объединенных Наций по вопросам образования науки и культуры  Intergovernmental Oceanographic
Commission

 Commission
océanographique intergouvernementale

Comisión Oceanográfica Intergubernamental

Межправительственная океанографическая комиссия

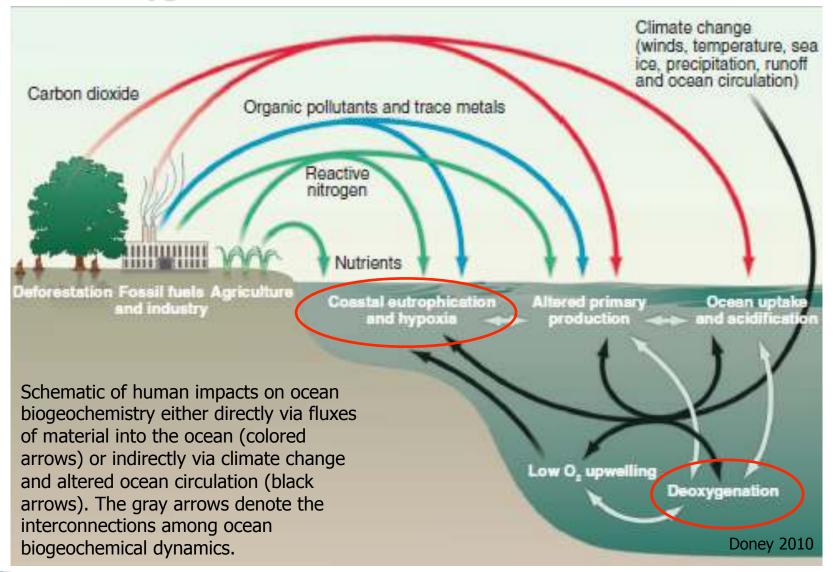
# The Ocean is Losing its Breath

#### Kirsten Isensee

Intergovernmental Oceanographic Commission of UNESCO

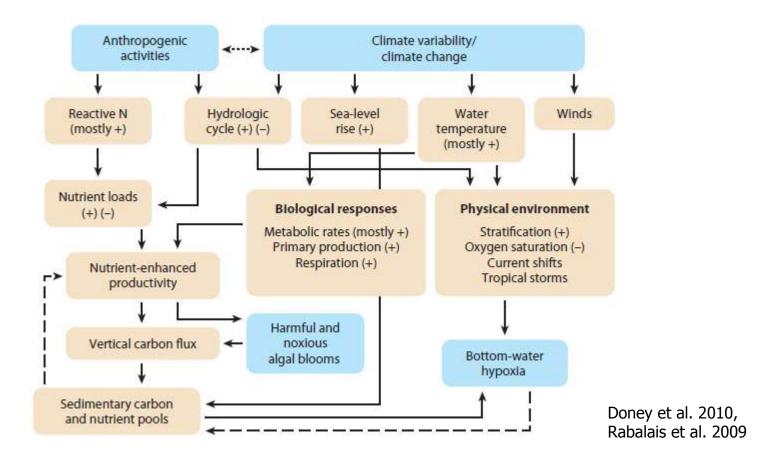
Brest, 18 May 2015

### **Deoxygenation of coastal and oceanic waters**





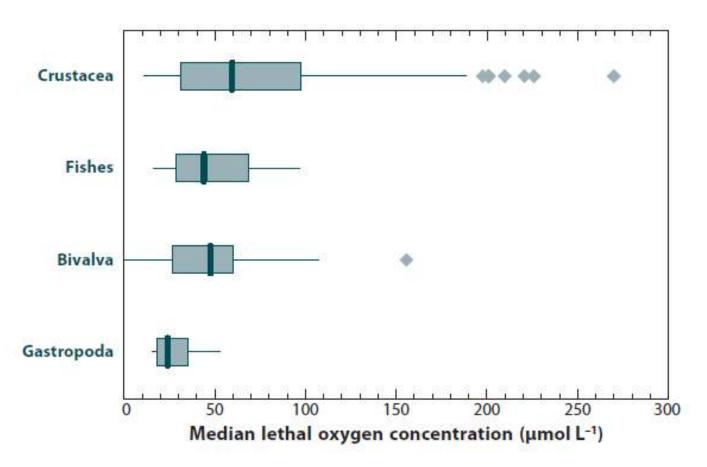
## **Deoxygenation of coastal and oceanic waters**



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.



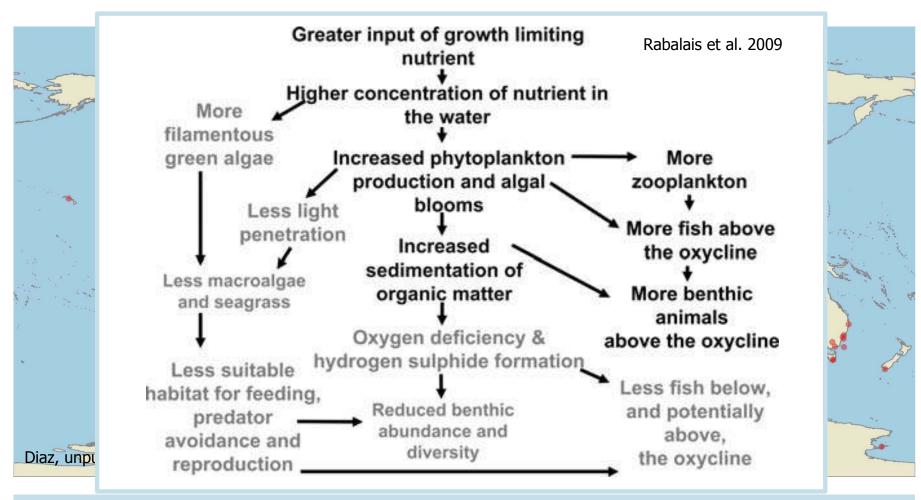
## Taxa depending impact of deoxygenation



Keeling et al. 2010



### **Deoxygenation of coastal waters – Dead Zones**



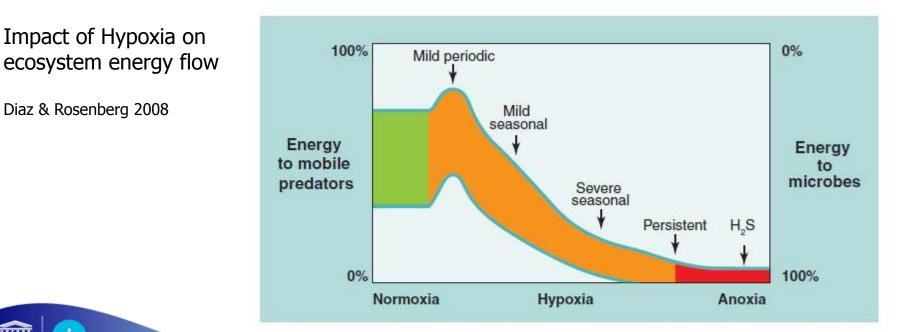
Schematic representation of the cascading effects of increasing nutrients in a coastal ecosystem. The harmful effects of nutrient over-enrichment are presented in grey letters.



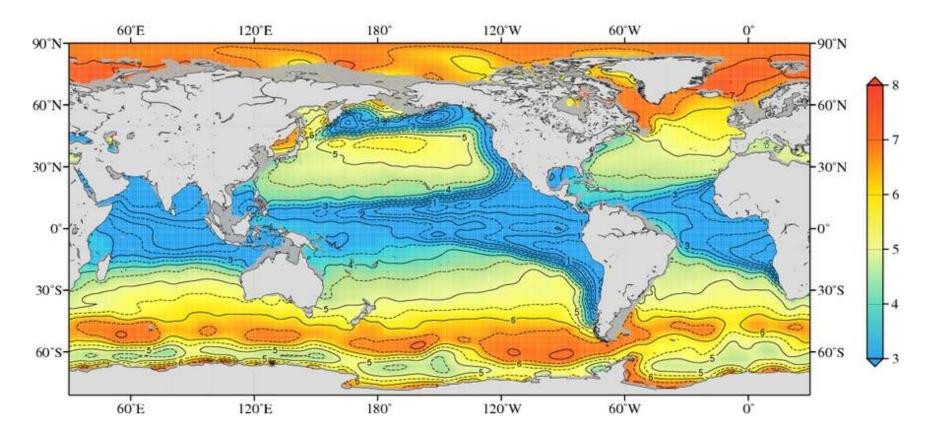
### **Deoxygenation of coastal waters – Dead Zones**

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<sub>4</sub>, N<sub>2</sub>O), 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.



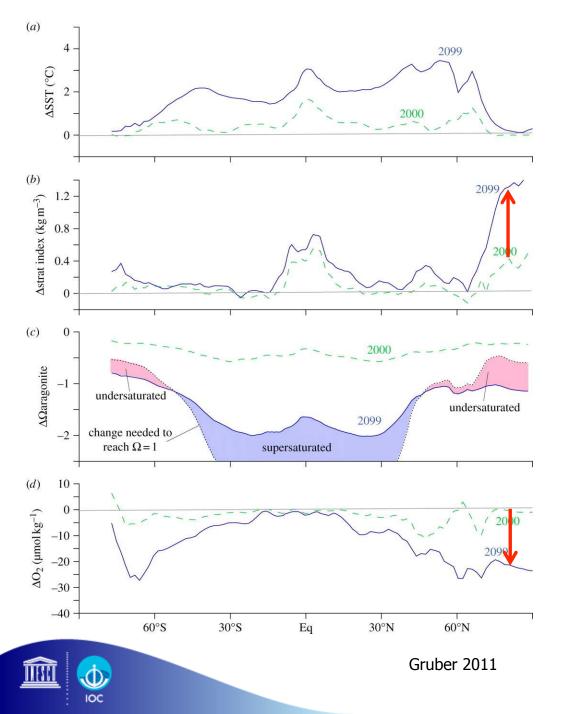
### **Deoxygenation of oceanic waters – Oxygen Minimum Zones**



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

World Ocean Atlas 2013, Garcia et al. 2014



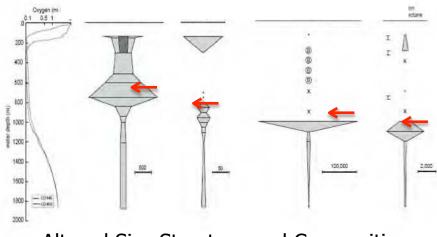


Zonal mean profiles of modelsimulated changes in ocean properties for 2099 (under the IPCC SRES A2 scenario) and 2000 relative to the year 1850 (atmospheric  $CO_2 - 1850$ : 280 ppm; 2000: 370 ppm; 2099: 840 ppm).

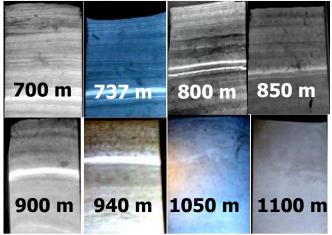
- a) Change in sea-surface temperature;
- b) change in upper ocean stratification, density gradient between 0–50 m and 100–200 m;
- c) change in the surface aragonite ocean saturation state;
- d) change in the mean concentration of oxygen in the thermocline (200–600 m).

Results are from the NCAR CSM 1.4 model.

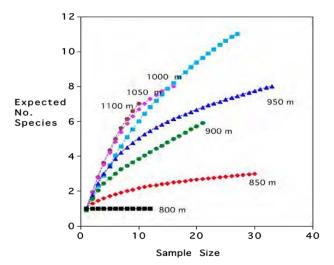
### Multiple consequences of low oxygen in OMZs



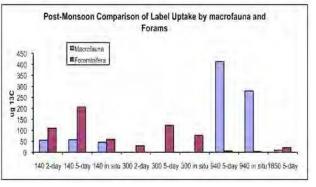
Altered Size Structure and Composition



#### **Reduced Bioturbation**







#### Rapid Biodiversity Shifts

#### Reduced Colonization

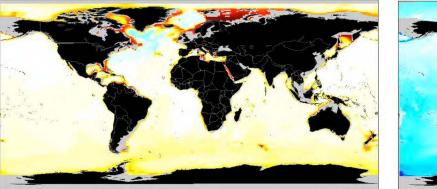
#### Altered Carbon Processing

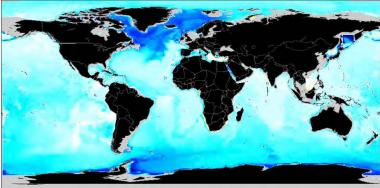


Would et al. 2007; Levin et al. 2009; Gooday et al. 2009; Levin et al. 2013

### **Projections of oceanic waters – Bottom Waters**

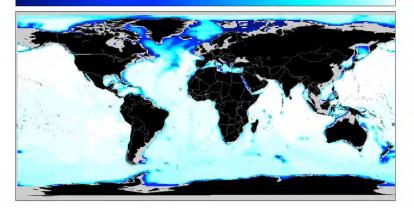
∆ Temperature (° C) 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5  $\Delta \text{ Dissolved Oxygen (ml L}^{-1})$ -0.040 -0.035 -0.030 -0.025 -0.020 -0.015 -0.010 -0.005 0.000

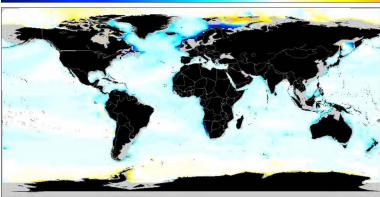




∆ pH -0.35 -0.30 -0.25 -0.20 -0.15 -0.10 -0.05

 $\Delta \text{ Seafloor POC flux (mg C m}^{-2} \text{ day}^{-1})$ -8 -6 -4 -2 0 2



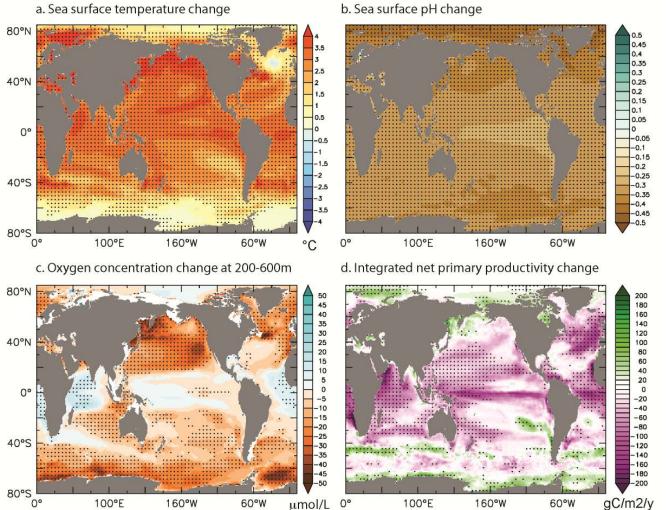


Mora et al. 2013



Projected Change on the Deep-Sea Floor - 2100

## **Projections of oceanic waters – Surface Waters**



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

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.

## **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

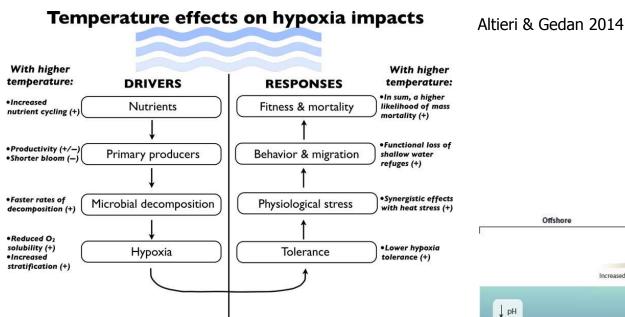
 Negative impact on functional attributes of communities, e.g. biodiversity, resilience, food-web structure

Loss of ecological services, human depend on –

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



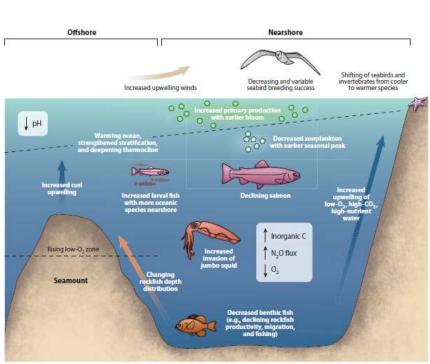
## **Multiple Stressor Challenge**



Summary of climate-dependent changes in the California Current.

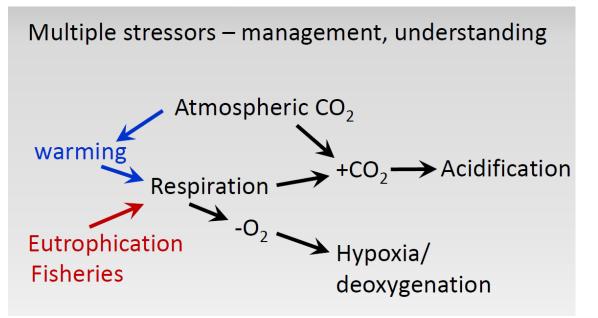
Observed physical changes include:

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





## **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



- **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



#### Nº 488 + 6,40€ JUIN 2014



#### Environnement La mer Baltique étouffe de plus en plus

a Baltique, future mer morte? Lorsque l'eau a une concentration d'oxygène dissous inférieure à 2 milligrammes par litre, la vie n'y est presque plus possible. Or, en un siècle, les zones sous-oxygénées ont été multipliées par dix en mer Baltique, selon Jacob Carstensen, de l'université d'Aarhus, au Danemark, et des confrères suédois [1]. Ce constat alarmant découle de l'analyse des données de salinité, de température et d'oxygénation recueillies entre 1898 et 2012 dans deux grands bassins situés autour fond des bassins, ces eaux se

de l'île de Gotland, entre la

Suède et la Lettonie Plus précisément, les zones sous-oxygénées de profondeur seulement. Les wysterns, the air we i we drink.

#### Linking coasts and seas to address ocean deoxygenation

Accelerated oxygen loss in both coastal and open oceans is generating complex biological responses; future understanding and management will require holistic integration of currently fragmented oxygen observation and research programmes.

Description of the cents non of the cents of	Interest in advectorability insegments and advectories. In advectories in the second of the se	int di se un provincia da la composicia
--	--	---





LES ZONES SOUS-OXYGENEES (en rouge) et celles

superficie totale d'environ pas contentés de décrire 400 000 kilomètres carcette évolution néfaste. rés. En outre, alors qu'elles Ils ont aussi modélisé les n'étaient présentes qu'au mécanismes physiques et biologiques à l'origine de rapprochent de la surface : cette désoxygénation, afin elles se situent maintede comparer leur influence nant à quelque 50 mêtres de respective.



sièurs années ralentit ce

Or, le réchauffement climatique en cours depuis plu-

Nd

unity | oxygen | coastal ecosystems | eutrophica

D issolved oxygen in coastal waters has changed drastically ecologically important variable (1, 2), leading to the widespread occurrence of hypoxia. An assessment of the literature shows that the number of coastal sites where hypoxin has been reported

REVIEW

**Changing Oceans** 

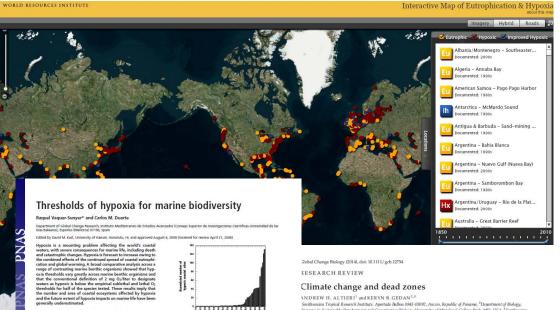
(13). Marine biogeochemical dynamics is increased

Marine biogeochemical dynamics is increas-ingly relevant to discussion of cocyastembaldh, climate impacts and miligation wherefore, and perturbations overlap used and the second second chillenges involves used small naturation of decadal and longer tensh in ocean chemistry as well as more definitive assessments of the resulting implications for ocean life and marine resources.

resources. The biogeochemical state of the sea reflects both cycling and transformations within the ocean, much of which are governed by biological dy-namics, and fluxes across the ocean boundaries in the local characteristic methan 0 area (2, 1, 0) with the land, atmosphere, and sea floor (2, 14) For most chemical species, seawater concentra-

1512

A global net



3lobal Change Biology (2014), doi: 10.1111/gcb.12754

RESEARCH REVIEW

#### Climate change and dead zones

AND REW H. ALTIERI<sup>1</sup> and KERYN B. GEDAN<sup>2,3</sup>

Smithisonian Tropical Research Institute, Apartado Balboa 0843-03092, Ancon, Republic of Panama, <sup>2</sup>Department of Biology, <sup>2</sup>rogram in Sustainable Development and Conservation Biology, University of Maryland, College Park, MD, USA, <sup>3</sup>Smithsonian nvironmental Research Center, Edorwater, MD, USA

#### Abstract

istuaries and coastal seas provide valuable ecosystem services but are particularly vulnerable to the co-occurring hreats of climate change and oxygen-depleted dead zones. We analyzed the severity of climate change predicted for scisting dead zones, and found that 94% of dead zones are in regions that will experience at least a 2 °C temperature nd of the century. We then reviewed how climate change will exacerbate hypoxic conditions through

cological, and physiological processes. We found evidence that suggests numerous climate variables xxological, and physicological processes. We bound evidence that suggests numerous climate variables arture, cocan aciditationis, seal-evide rise, precipitation, wind, and storm pattens will affect deal each of those factors has the potential to act through multiple pathways on both oxygen availability upponess to hyposia. Given the variable and strength of the mechanisms by which climate change oxia, and the rates at which climate is changing, we posit that climate change variables are contributtone epidemic by acting synergistically with one another and with recognized anthropogenic triggers the epidemic by acting syne gestuary with one another and with recognized antimpopulation triggers iding eutrophication. This suggests that a multidisciplinary, integrated approach that considers the nate variables is needed to track and potentially reverse the spread of dead zones. ed oxygen, ecosystem function, estuaries, eutrophication, hypoxia, ocean acidification, sea-level rise

their consumption of phytoplankton at the same time that nutrients are stimulating primary productivity (Jackson et al., 2001; Lotze et al., 2006).

The link between eutrophication and severity of

hypoxia is modulated by factors including runoff, water column stratification, primary productivity, microbial activity, and organismal respiration. Based on the wide variety of ways in which climate

change can influence these factors through tempera-

ture, ocean acidification (OA), sea-level rise, precipi tation, winds, storm frequency, and other variables

(Fig. 1), we suggest that climate change is likely contributing to the observed increase in dead zones. Many of the early studies on links between climate,

eutrophication, and/or dead zones focused primarily on the potential for shifts in precipitation to affect

freshwater discharge and associated nutrient dynam-ics. These studies highlight the important link

between runoff and eutrophication, with important

implications for hypoxia, but this is only one of

many potential climate-related impacts on nutrients

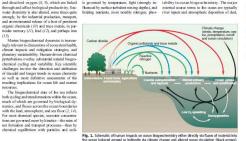
and/or dead zone formation (Howarth et al., 2000; Struyf et al., 2004; Justic et al., 2005). Evidence is

accumulating from some ecosystems that the effects of climate are sufficiently strong enough to further increase the severity of dead zones, even if rates of

914; revised version received 27 August 2014 and accepted 28 August 2014

phorus, iron, and silicon for some plankton. Some fraction of the biologically produced particulate matter subsequently sinks into the subsurface

dead zones is linked to higher rates of making the dead zone epidemic one of



................

in the literature (1, 12, 13) are based on limited observations of impacts on organisms (7), and a thorough empirical assessment of

 $P \simeq 0.01$ ).

tions are governed more by kinetics-the rates of net formation and transport processes-than by chemical equilibrium with particles and sedi-Fig. 1. Schematic of human impacts on excess Moreochemistry other dendly de faces of material in the ocean closered arrando or inderectly de clinese change and altered oxean circulation. Block arrando the goay arrando schematic de interconnections and oceanist calculations. We face that many ocean processes are all lect ob primitipies stressors, and the sprengistic effects of human perturbations is alway mark for tuber research. rine Chemistry and Geochemistry Department, Woods

18 JUNE 2010 VOL 328 SCIENCE www.sciencemag.org

ited by the depletion of dissolved tal waters are one of the most wideetrimental anthropogenic threats to ms worldwide and have been douince each decade since the mid-1900s & Rosenberg, 2008; Vaquer-Sunyer & oday et al., 2009; Rabalais et al., 2010). significant consequences for the biodictioning of marine ecosystems and the Frovide to society, including fisheries piter column filtration, and nutrient & Witman, 2006; Breitburg et al., 2009; 9; Levin et al., 2009; Diaz & Rosenberg, nential increase in the number, size,

17

<section-header><section-header><section-header><text><text><text><text><text><text>

uments for controlling eutrophication

demise of many grazer populations is

effect of nutrient loading by reducing

frew H. Altieri, Unit 9100 Box 0948, DPO AA

L + 1 202 633 4700 ext. 8727, e-mail: altieria@si.edu & Sons Ltd

erg, 2008; Gooday et al., 2009; Rabalais



# **Thank you!**

**Kirsten Isensee** 

Ocean Science Section – Intergovernmental Oceanographic Commission of UNESCO

k.isensee@unesco.org

http://ioc.unesco.org

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

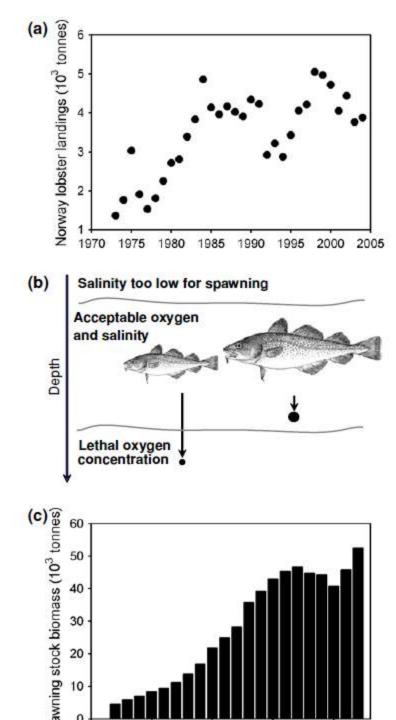


Fig. 4 Strong interactions between fisheries mortality and eutrophication occur because of effects of eutrophication on behaviors, effects of fisheries removals on population size structure, and because of the magnitude of mortality caused by fisheries exploitation. a Behavior: Norway lobster. Behavioral 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