Climate Change Impacts on Marine Ecosystems

Photo: Keith Ellenbogen I explorers.neag

Energy Flow & Ecosystem Functions

Marine ecosystems are maintained by the flow of energy

Climate Changes and Rising CO2

The physical environment

b

Rising Sea Level

Trends in Relative Sea Level Along U.S. Coasts, 1958-2008

 EPA **United States Environmental Protection Agency**

1960 2000 2005 2010 Time (yr) **Rising Upper Ocean Temperature**

 T emperature

peratur

0.00 0.05

Rising Upper Ocean Temperature

OBSERVATIONS: *Trends in degrees over 50 years Pierce et al. 2012*

Figure 1. Basin zonal-mean trends of salinity (upper, PSS-78/50 yrs) and temperature (lower, !C/50 yrs) averaged in the **CLIMATE MODELS:** *Attribution of anthropogenic signature* (left) Pacific, (middle) Atlantic, and (right) Indian ocean basins. For each variable, (top) the Levitus observations are shown,

and (bottom) the ensemble averaged model result are shown. Note the non-linear depth scale.

L21704 Changes in Upper Ocean Salinity and AT

OBSERVATIONS: *Trends in PSU over 50 years*

Pierce et al. 2012

CLIMATE MODELS: *Attribution of anthropogenic signature*

Fingerprinting Human Induced Changes

Human Induced Changes in Ocean pH

Ocean Carbon Dioxide Levels and Acidity, 1983-2005

Data source: Bindoff, N.L., J. Willebrand, V. Artale, A. Cazenave, J. Gregory, S. Gulev, K. Hanawa, C. Le Quéré, S. Levitus, Y.
Nojiri, C.K. Shum, L.D. Talley, and A. Unnikrishnan. 2007. Observations: Oceanic climate chang change 2007: The physical science basis (Fourth Assessment Report). Cambridge, United Kingdom: Cambridge University Press.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climatechange/science/indicators.

Climate Changes impacts on Oxygen

Is the Ocean loosing oxygen?

Oxygen Trends @300m 1960-2010

source: Stramma et al. GEOMAR

Climate Changes impacts on Oxygen

Is the Ocean loosing oxygen?

APO gradient (per meg) 0 Atmospheric potential oxygen –10 gradient –20 Nodal maxima 250 Western N. Pacific (Oyashio) σ_τ = 26.8 200 **ff. Corr. coe** 0.5 Dissolved O₂ (µmol kg⁻¹) **Dissolved O2 (µmol kg–1)** 0.0 150 –0.5 0 2 4 6 8 1012 **Lag (years)** 0⁰⁰00₀0
0 100 ೲೲ 。^{ooooo}o。 ್ಗಂ Eastern N. Pacific 50 (Station P) $\sigma_{\tau} = 26.9$ 50 - 90 Eastern Eq. Pacific 200–700 m average سا 0
1950 1950 1960 1970 1980 1990 2000 2010 **Year**

Long-term Observations in the Pacific

 $\overline{}$ *Keeling et al., 2010*

Figure 7

by University of California - San Diego on 11/14/12. For personal use only.

Expanding Oxygen Minimum Zones (OMZ)

Warming, reduced ventilation from stratification and circulation changes may contribute to an expansion of the OMZs

decomposition in a warming world must therefore be considered in close considered in close concert with the effects of \mathcal{L} **Sensitivity of Ocean Taxa to Oxygen** At very low O2 concentrations, major changes in biogeochemical cycling occur. When O2

"dead zones" for many higher animals. As a complication, the thresholds for the thresholds for hypoxia typical

 α eling at also 2010. The whiskers show the whiskers show the location of t withing et al., 2010 are outliers as per this definition. Redrawn after a per this definition. Redrawn after a
In 1980 and 2010 and

Coastal Hypoxia: The Dead Zones

HOW THE DEAD ZONE FORMS

1. Spring Stratification from heating and freshwater

2. Nitrogen Inputs & Blooms

to the surface (e.g. river runoff or upwelling) trigger blooms Flux of organic matter to the

deep

of organic induces oxygen depletion in

the deep

3. Respiration

Climate Changes impacts on Oxygen

Costal Hypoxia is increasing leading to Dead Zones

Fig. 1. Global distribution of 400-plus systems that have scientifically reported accounts of being eutrophication-associated dead zones. Their distribution matches the global human footprint [the normalized human

influence is expressed as a percent (41)] in the Northern Hemisphere. For the Southern Hemisphere, the occurrence of dead zones is only recently being reported. Details on each system are in tables S1 and S2.

Causes

✤ **Increase the amount of bioavailable nitrogen runoff** ✤ **Expansion of OMZs**

Ecosystem Response to Climate

Physical and chemical changes have strong direct and indirect effects on the physiology and behavior of marine organisms.

Types of Response:

◆ Physiological responses ← Population and Community Responses ← Ecosystem Structure and Function

Physiological Responses

Environmental Change / Types of Response:

✦ **Temperature & Oxygen** --> **Metabolic Rates Constraint** adaptation, migration or extinction

Ocean Acidification --> Calcification

lost of biogenic habitats (e.g. corals reefs and oyster beds) alteration of food webs (e.g. pteropods and mollusks) changes in global bio-geochemical cycles (e.g. coccolithophore algae)

Physiological Responses

Environmental Change / Types of Response:

✦ **Temperature & Oxygen** --> **Metabolic Rates Constraint** adaptation, migration or extinction

Define: **Metabolic Index = -**

Oxygen Supply

Oxygen Demand (depends also on Temperature)

Distribution data: Cod **F** = Metabolic Index (contour maps)

Cod Characteristics:

Depth of habitat 0-400m Mass at maturity 500-1500g Range of F_{crit} 1.3-2.6

Metabolic Index (contour maps)

Seasonal Migration

Metabolic Index (contour maps)

Species Distribution: Seabream

Seabream Characteristics:

Depth of habitat 0-60m Mass at maturity 300-900g Range of F_{crit} 1.6-4.0

Distribution data digitized from Andriashev 1986 and Van Neer 1997

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Metabolic Index (contour maps)

Species Distribution: Eelpout

Eelpout Characteristics:

Depth of habitat 0-40m Mass at maturity 100-300g Range of F_{crit} 1.4-3.3

Distribution data digitized from Svetodvidov 1986

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Climate Change impacts on Metabolic Index

Climate Projections

Projected T, $O₂$ changes in 2071-2100, 0-400m IPCC Earth System Model mean, RCP8.5 scenario

Warming is global, deoxygenation is extra-tropical.

Declining Metabolic Index **Climate Change impacts on Metabolic Index**

Temperature [^o

Global mean Decrease ~20%

Northern High Latitudes ~40%

−50 −45 −40 −35 −30 −25 −20 −15 −10 −5 0 60° F 120° E 180° W 120° W 60° W W 0° 60° S $30^{\rm o}$ S Ω 30° N 60° N −50 −45 −40 −35 −30 −25 −20 −15 −10 −5 0 $60^{\circ}E$ $120^{\circ}E$ 180° W 120° W $\overline{60^{\circ}}$ W W 0^o $|60^{\circ}S|$ $|30^{\circ}$ S n° 30° N $|60^{\circ}$ N DF_{02} (%) $_{02}$ (%) DF $DF_T(\%)$ **A** $\mathbb{R}^n \longrightarrow \mathbb{R}^n$ Temperature vs Oxygen Oxygen contribution Temperature contribution **Climate Change impacts on Metabolic Index** *courtesy of C. Deutsch (UCLA)*

Globally, warming and deoxygenation contribute ~15% and 5% reduction of metabolic index, respectively. The role of $O₂$ is greater in the Pacific, where O2 is already lower.

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Climate Change impacts on Metabolic Index

Metabolic Habitat Loss

Physiological Responses

Environmental Change / Types of Response:

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lost of biogenic habitats (e.g. corals reefs and oyster beds) alteration of food webs (e.g. pteropods and mollusks) changes in global bio-geochemical cycles (e.g. coccolithophore algae)

Ocean Acidification Forecasts

 $2 mm$

normal seawater

Photos of scleractinian coral Oculina patagonica after being maintained for 12 months in (a) normal seawater ($pH =$ 8.2) and (b) acidified seawater ($pH = 7.4$). From Fine & Tchernov (2007). Reprinted with permission from AAAS

acidified seawater

Ocean Acidification Forecasts

THREAT TO CORAL REEFS FROM OCEAN ACIDIFICATION IN THE PRESENT, 2030, AND 2050

Acidification may impact calcification in *Corals*

Population and Community Responses

Environmental Change / Types of Response**:**

✦ **Phenology** --> **Growing Season**

changes in primary productivity and predator/prey interaction, changes in net biomass

Ocean Warming --> Species Range

shifts in species distributions and niche boundaries (e.g. invasions) *changes in competition and local extinctions*

Population and Community Responses

Environmental Change / Types of Response**:**

✦ **Phenology** --> **Growing Season**

changes in primary productivity

and predator/prey interaction, changes in net biomass

poor recruitment and population decreases in future years. If persistent, decoupling of trophic linkages could have severe impacts on marine ecosystem orga-Mackas (2009), Schroeder et al. (2009), and Watanuki et al. (2009) were originally presented in that topic ses-Phenology: Timing of seasonal cycle

at the 16th Annual Meeting of the North Pacific Marine

communities. For example, a reduction in foraging effi-

Fig. 1. Schematic of how phenology (timing) and relative abundance (biomass) affect the degree of trophic match-mismatch (after Durant et al. 2005). The key variable is the degree of trophic overlap of predator needs (continuous line) and prey availability (dashed line) in time and space. Dashed curves reflect biomass of prey (height) and seasonality of prey abundance (position of maximum). Reproductive success and other demographic traits will be high when there is great trophic overlap (grey area under curves)

Population and Community Responses

Environmental Change / Types of Response:

Ocean Warming --> Species Range

shifts in species distributions and niche boundaries (e.g. invasions) *changes in competition and local extinctions*

Shift in Species Distribution

Ecosystem Structure and Function

Environmental Change / Types of Response**:**

← Ocean Circulation --> Species Compositions --> Nutrient Supply --> Connectivity

Ocean Transport and Species Composition structure

PDO holds many clues: e.g., changes in sign seem

Ecosystem Structure and Function

Environmental Change / Types of Response**:**

← Ocean Circulation --> Species Compositions --> Nutrient Supply --> Connectivity

sponse to the progressive build up of atmospheric Γ chemical. is concern that the Peruvian coastal upwelling system may weaken in the future. Opposing this particular concern are earlier premises $\bf B$ akun, 1990; Diffenbaugh et al., 2004) that prediction $\bf B$ intensification of coastal upwelling in major upwelling zones of the world as atmospheric greenhouse gas of the year (spring and summer in subtropical latitudes) year-round in tropical latitudes) when, because of **Changes in Nutrient Supplies in Eastern** compared with land surfaces, air temperature over a coastal landmass tends to increase relative to that **Boundary Upwelling Systems**

Throughout the world's oceans, coastal upwelling tends

dimentary studies accrue (Otto-Bliesner et al., 2003; **McGregor et al., 2007; Guide et al., 200**7, 2018 ical time series of recorded observations continue to lengthen (Bakun, 1998). **HOUGAN EXTRACTED SIMULATION** \mathbf{r} is a smaller pressure gradient supports of \mathbf{r} Upwelling winds may intensify **an offshore**directed Ekman transport of surface waters. When the surface waters are thereby forced offshore from the in response to climate change **for spatial scales too large for the spatial scales of the spatial scales of the**

winds in the equatorial Pacific have weakened in re-

concentrations increase. Moreover, corroboration of this prediction appears to be unfolding as credible paleose-

$h_{\rm eff}$ relative to the more slowly heating of the more slowly heating equatorward geostrophic wind stress on the sea surface that, in turn, drives of ocean surface water and corresponding upwelling upwelling upwelling upwelling u required to replace the surface waters transported offshore; (b) buildup of greenhouse gases in the atmosphere inhibits nighttime cooling

Intensification of Upwelling winds?

calculated by the method of least squares. All regions show a significant increase of upwelling.

J I

J I

Full Screen / Esc

Printer-friendly Version

Ecosystem Response to Climate

Physical and chemical changes have strong direct and indirect effects on the physiology and behavior of marine organisms.

Types of Response:

◆ Physiological responses \blacklozenge Population and Community Responses ← Ecosystem Structure and Function

We have reviewed some examples of responses, however the **ecosystem response is more complex and integrated.**

Additional Ecosystem Pressures Mean ocean-surface pH (total scale)

0–700-m ocean heat content (1022 J)

Sea-surface temperature (°C)

an integrated approach to Ecosystem Structure and the need for an integrated approach to Ecosystem Structure and Function

