CLIMATE-HUMAN-POLICY CONNECTIONS IN DEEP-OCEAN ECOSYSTEMS

Lisa A. Levin
Center for Marine Biodiversity and Conservation,
Scripps Institution of Oceanography

Chih-Lin Wei, National Taiwan University
William Cheung, Univ. British Columbia
Daniel Dunn, Duke University

Effects of Climate Change in the World Oceans
Washington DC, June 2018
Climate-Human-Policy Connections in the Deep

- Changing environments
- Climate confluence with human activities
- Building Climate into Management
  - Spatial Planning
  - Environmental Impact Assessment
- Science Diplomacy: A role for scientists and networks
The ocean as great climate mitigator

Heat

CO₂

Stratification

93%

26%

Productivity decline

Oxygen Loss
Thermohaline circulation and convection leads to a warmer, more acidic, less oxygenated ocean.
Projected changes on the deep-sea floor
RCP 8.5 Change from 1951/2000 to 2080-2100 at the sea floor

- Export POC Flux Difference (mg C m⁻² day⁻¹)
- Dissolved Oxygen Difference (µmol kg⁻¹)
- pH Difference
- Temperature Difference (°C)

POC Flux
O₂
pH
Temp

Wei et al. 2018 and Sweetman et al. 2017
Ch8, Deep-Ocean climate change impacts on habitat, fish and fisheries. FAO
Growing human pressures in the deep ocean ...

Bottom Trawling

Seabed Mining

OMZs  Vents

Abyssal plains

Seamounts

Abyssal plains

OMZs  Vents

Mine tailings Disposal

Debris

Ferromanganese crusts on a seamount (GARMCH, AAB)

Seamounts

Ferromanganese crusts on a seamount (GARMCH, AAB)
Bring disturbance...

- **PHYSICAL DISRUPTION**
- **CONTAMINATION**
- **LOSS OF STRUCTURE**
- **SUSPENDED SEDIMENT PLUME**
- **BYCATCH**
- **ALTERED SUBSTRATE**
How will climate change interact with human disturbance?
Temperature interaction with seabed mining

Rising temperatures can:
- Increase metabolic demand
- Redistribute species & biogenic habitat
- Reduce tolerance to other stressors

Wei et al. 2018

RCP 8.5 Change from 1951/2000 to 2080-2100
pH interaction with seabed mining

Reduced pH and saturations state ($\Omega$) can cause:

- Loss of calcifiers
- Dissolution and bioerosion of non-living carbonate habitats
- Increased energy demands for acid-base regulation
- Impaired behavior
- Slowed coral recovery from mining disturbance

RCP 8.5 Change from 1951/2000 to 2080-2100

Wei et al. 2018
Oxygen interaction with seabed mining

O$_2$ decline causes
- Loss of biodiversity and foundation sp.
- Redistribution & habitat compression
- Changing food webs
- Exacerbated biogeochemical stress from mining

Wei et al. 2018

Ch8, Deep-Ocean climate change impacts on habitat, fish and fisheries. FAO

RCP 8.5 Change from 1951/2000 to 2080-2100
POC flux interaction with seabed mining

Reduced food supply can cause:
- Less biomass
- Smaller body size
- Slow recovery from mining disturbance
- Problems coping with other stressors

Wei et al. 2018
Ch8, Deep-Ocean climate change impacts on habitat, fish and fisheries. FAO

RCP 8.5 Change from 1951/2000 to 2080-2100
Hydrocarbon leakage and spills: Deoxygenation compounded
Reduced resilience and recovery from contamination
Climate change interaction with bottom fisheries

Vulnerable Marine Ecosystems

Fish: Habitat, Distributions, Body Size, Food webs

See S6 talks by Morato Carreiro-Silva Cheung
How can we incorporate climate into management of the deep-sea floor?
International management of deep-ocean activities.

The seafloor in regions targeted for mining.

The seafloor in regions targeted for bottom fishing, tuna.

Figure from chapter by Ardron & Warner, in Handbook of Ocean Resources, Earthscan Books.
A Role for Climate

- Spatial Planning and Creation of Protected Areas
- Environmental Impact Assessment
  - Baseline Data & Monitoring
  - Cumulative Impacts
- Capacity Building & Technology Transfer
SEABED MINING

The International Seabed Authority has a mandate: **To adopt measures necessary to ensure effective protection of the marine environment**

Areas of Particular Environmental Interest (APEIs) = no-mining areas

- Important Areas
- Representativity
- Connectivity
- Replication
- Viability & Adequacy

SEMPIA PLANNING

100, 200, 300, 400-km wide APEI scenarios

Incorporating projected climate change into assessment of different APEI scenarios

Dunn et al. in press

*Science Advances*
Projected Climate Change in 200, 300, 400-m wide APEI scenarios

Do we protect the least vulnerable areas as refugia? or the most vulnerable areas to enhance resilience?

Deep-sea Fisheries: RFMOs must consider climate change impacts

United Nations General Assembly resolution 71/123 2016

Paragraph 185. Calls upon States, individually and through regional fisheries management organizations and arrangements, “to take into account the potential impacts of climate change and ocean acidification in taking measures to manage deep-sea fisheries and protect vulnerable marine ecosystems”
Southeast Atlantic Fisheries Organization

Climate Change Projections 2041-2060, RCP 8.5

Wei et al. 2018
Ch8, Deep-ocean climate change impacts on habitat, fish and fisheries. FAO
Northeast Atlantic Fisheries Commission

Climate Change Projections 2041-2060, RCP 8.5

Wei et al. 2018
Ch8, Deep-Ocean climate change impacts on habitat, fish and fisheries. FAO

<table>
<thead>
<tr>
<th>NEAFC</th>
<th>POC Flux</th>
<th>Oxygen</th>
<th>pH</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;200 m</td>
<td>-0.22</td>
<td>-7.11</td>
<td>-0.04</td>
<td>-0.01</td>
</tr>
<tr>
<td>200-2 500 m</td>
<td>-0.62</td>
<td>-4.42</td>
<td>-0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>Bottom fishing area</td>
<td>-2.2</td>
<td>13.9</td>
<td>-0.12</td>
<td>0.56</td>
</tr>
<tr>
<td>VMI: closed area</td>
<td>-0.27</td>
<td>-13.51</td>
<td>-0.09</td>
<td>-0.14</td>
</tr>
<tr>
<td>Cold-water corals</td>
<td>-0.44</td>
<td>-10.23</td>
<td>-0.1</td>
<td>0.01</td>
</tr>
<tr>
<td>Canyons</td>
<td>-0.58</td>
<td>8.74</td>
<td>-0.09</td>
<td>-0.05</td>
</tr>
</tbody>
</table>
Time of Emergence
(when the climate signal exceeds natural variability)

- Identify the most imminent threats
- Identify areas with least change to act as refugia

All areas will exceed natural variability for all parameters before 2060

<table>
<thead>
<tr>
<th>NEAFC</th>
<th>POC Flux</th>
<th>Oxygen</th>
<th>pH</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;200 m</td>
<td>2057</td>
<td>2044</td>
<td>2044</td>
<td>2050</td>
</tr>
<tr>
<td>200-2 500 m</td>
<td>2048</td>
<td>2045</td>
<td>2039</td>
<td>2041</td>
</tr>
<tr>
<td>Bottom fishing area</td>
<td>2051</td>
<td>2037</td>
<td>2028</td>
<td>2027</td>
</tr>
<tr>
<td>VMF closed area</td>
<td>2048</td>
<td>2043</td>
<td>2029</td>
<td>2037</td>
</tr>
<tr>
<td>Cold-water corals</td>
<td>2052</td>
<td>2049</td>
<td>2032</td>
<td>2041</td>
</tr>
<tr>
<td>Canyons</td>
<td>2043</td>
<td>2043</td>
<td>2031</td>
<td>2040</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SEAFO</th>
<th>POC Flux</th>
<th>Oxygen</th>
<th>pH</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;200 m</td>
<td>2047</td>
<td>2046</td>
<td>2042</td>
<td>2050</td>
</tr>
<tr>
<td>200-2 500 m</td>
<td>2048</td>
<td>2039</td>
<td>2039</td>
<td>2041</td>
</tr>
<tr>
<td>Bottom fishing area</td>
<td>2042</td>
<td>2040</td>
<td>2039</td>
<td>2048</td>
</tr>
<tr>
<td>VMF closed area</td>
<td>2044</td>
<td>2044</td>
<td>2041</td>
<td>2053</td>
</tr>
<tr>
<td>Scamounts</td>
<td>2040</td>
<td>2040</td>
<td>2042</td>
<td>2053</td>
</tr>
<tr>
<td>Cold-water corals</td>
<td>2046</td>
<td>2048</td>
<td>2044</td>
<td>2042</td>
</tr>
<tr>
<td>Canyons</td>
<td>2046</td>
<td>2040</td>
<td>2037</td>
<td>2044</td>
</tr>
</tbody>
</table>

Cumulative Climate Hazard

Wei et al. 2018
Ch8, Deep-Ocean climate change impacts on habitat, fish and fisheries. FAO
Climate and Spatial Planning

- Climate change can affect **connectivity** of populations and protected areas.

- Climate change can alter **habitat suitability**, redistribute species, alter biomass and modify biodiversity.

---

**Connectivity of MPAs**

Fox et al. 2016

**Biodiversity Loss**

Cheung et al. 2016

**Climate change impacts on habitat, fish and fisheries. FAO**

Ch 10 Morato et al. in *Deep-Ocean climate change impacts on habitat, fish and fisheries*. FAO

Mitarai et al 2016, PNAS
A role for climate in ‘BBNJ’

Development of an international legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction

Possible BBNJ elements:

I. Area-based management tools (including MPAs)
II. Environmental impact assessments
III. Marine genetic resources
IV. Capacity building and the transfer of marine technology

Ecologically and Biologically Significant Areas

Cumulative Climate Impact

North Atlantic

Johnson et al. 2017

Ch8, Wei et al. in Deep-ocean climate change impacts on habitat, fish and fisheries. FAO
Climate and Environmental Impact Assessment

**EIA Required**
- Seabed mining (ISA)
- Deep sea fishing (FAO)
- Dumping of wastes + marine geoengineering research (IMO)

**EIA Not Currently Required**
- Pelagic Fishing
- Hydrocarbon extraction
- Shipping discharge
- Bioprospecting
- Ocean Energy
- Aquaculture
- Cables and Pipelines
- Tourism

**BASELINE STUDIES & MONITORING:**
* measure climate variables (T, S, O2, Carbonate System, POC flux)
* vulnerabilities to climate

**TRIGGERS AND THRESHOLDS** for carrying out EIAs/SEAs; decision making, serious harm

**CUMULATIVE EFFECTS** of targeted activity with climate-induced changes
(in combination with contaminants, particles, biota, microbes)

**IMPACTS ON ECOSYSTEM SERVICES**
made more vulnerable to physical disturbance by climate change
Can we put our observing programs to work to help incorporate climate into ecosystem-based management of the deep ocean?

• New deep-ocean observations, technologies & coordination

WHAT?? WHERE?? WHEN??

Application of genomics to impact and climate change assessment?

Figure 2. Schematic representation of the “Meta” levels in the ecology of microbial communities.

Maron et al. 2007
Inventory of Sustained Deep-Ocean Observing

Integrate climate observing into ecosystem-based management of the deep ocean

Essential Ocean Variables (for the Deep)

<table>
<thead>
<tr>
<th>PHYSICS</th>
<th>BIOGEOCHEMISTRY</th>
<th>BIOLOGY AND ECOSYSTEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea state</td>
<td>Oxygen</td>
<td>Phytoplankton biomass and diversity</td>
</tr>
<tr>
<td>Ocean surface stress</td>
<td>Nutrients</td>
<td>Zooplankton biomass and diversity</td>
</tr>
<tr>
<td>Sea ice</td>
<td>Inorganic carbon</td>
<td>Fish abundance and distribution</td>
</tr>
<tr>
<td>Sea surface height</td>
<td>Transient tracers</td>
<td>Marine turtles, birds, mammals</td>
</tr>
<tr>
<td>Sea surface temperature</td>
<td>Particulate matter</td>
<td>abundance and distribution</td>
</tr>
<tr>
<td>Subsurface temperature</td>
<td>Nitrous oxide</td>
<td>Live coral</td>
</tr>
<tr>
<td>Surface currents</td>
<td>Stable carbon isotopes</td>
<td>Seagrass cover</td>
</tr>
<tr>
<td>Subsurface currents</td>
<td>Dissolved organic carbon</td>
<td>Macroalgal canopy</td>
</tr>
<tr>
<td>Sea surface salinity</td>
<td>Ocean colour \text{(Spec Sheet under development)}</td>
<td>Microbe biomass and diversity \text{(emerging)}</td>
</tr>
<tr>
<td>Subsurface salinity</td>
<td></td>
<td>Benthic invertebrate abundance and distribution \text{(emerging)}</td>
</tr>
</tbody>
</table>
CLIMATE - HUMAN - POLICY CONNECTIONS

Putting our knowledge to work

To enable sustainability in the deep ocean

Biodiversity
EBSAs/VMEs
Cumulative Climate Hazards
CC Time of Emergence
Offshore Oil and Gas
Seabed Mining
Fishing Activity/Bycatch
Deep-Ocean Observing
Inform Sustainability:

- Where to make new deep ocean observations.
- Essential ocean variables for deep-sea sustainability
- Effective spatial planning in the deep ocean
- Improved Environmental Impact Assessment
- New research directions
A new role for deep-sea scientists

**SCIENCE DIPLOMACY**

**INTERNATIONAL NETWORK FOR SCIENTIFIC INVESTIGATIONS OF DEEP-SEA ECOSYSTEMS**

www.indeep-project.org

**OBSERVING/ EXPLORATION**

**DEEP OCEAN OBSERVING STRATEGY**

www.deepoceanobserving.org
Acknowledgements

• Special thanks to Chih-Lin Wei, Daniel Dunn, William Cheung
• Also to Matt Gianni Kristina Gjerde, Nadine LeBris, Tony Thompson, Maria Baker, Telmo Morato, Natalya Gallo, Sarah DeLand
• DOSI, DOOS, SEMPIA, FAO contributors
• PICES/ECCWO for travel support