marine Carbon Dioxide Removal as an ocean solution to climate change

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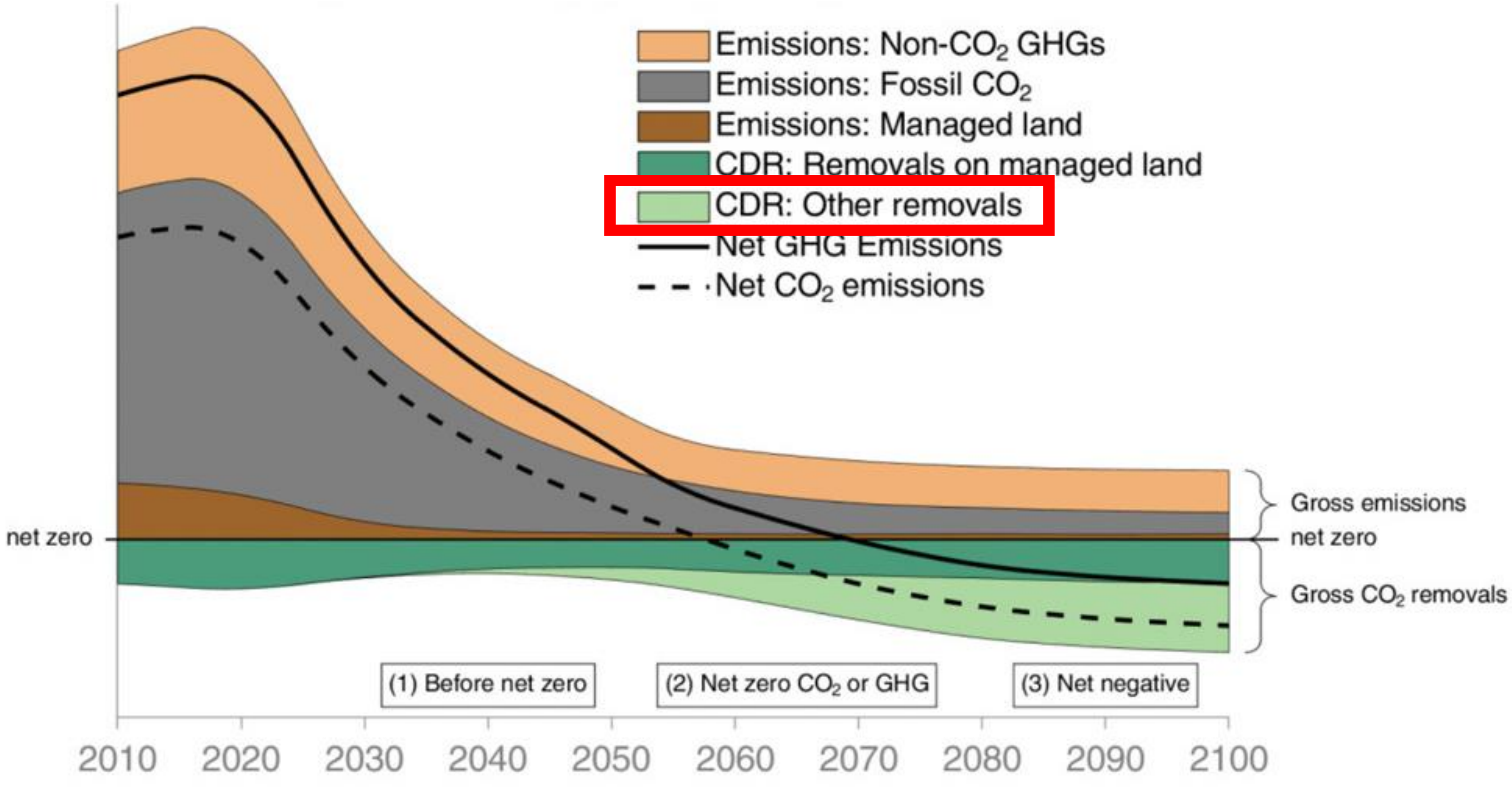
Commission Meeting

September 2023

The ocean is being considered as a necessary resource in CO_2 removal from the atmosphere

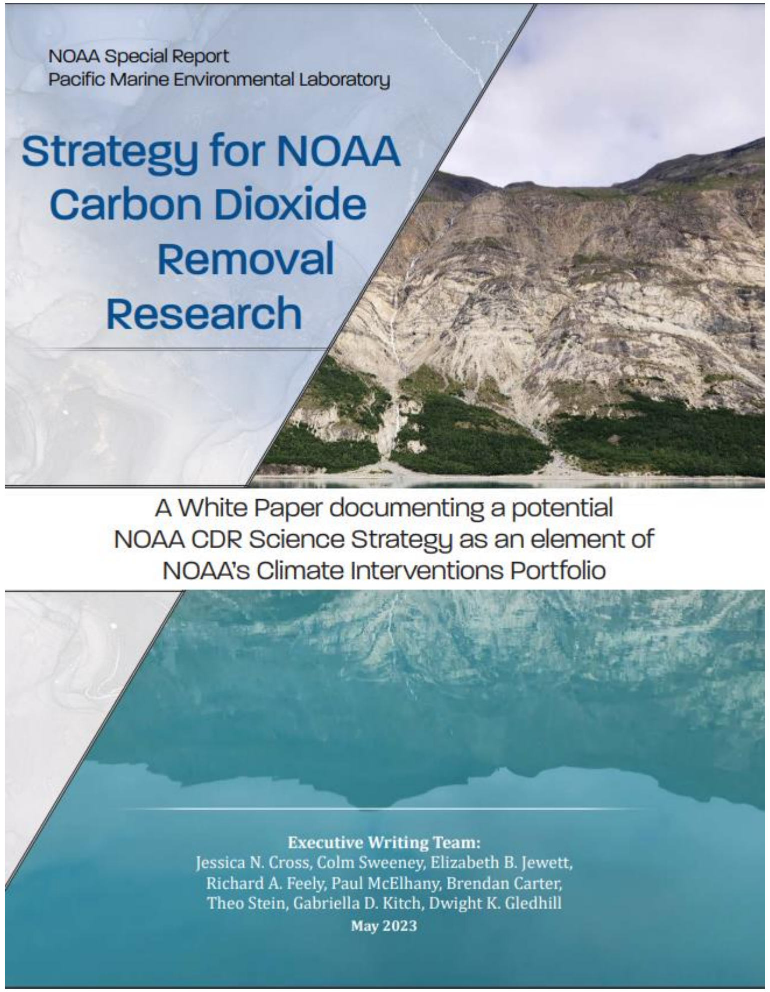
- **mCDR** = human activities in the ocean that remove CO_2 from the atmosphere
- Current estimates are that mCDR needs to contribute **50%** of required CO_2 removal



Source: IPCC

The mCDR field is upcoming and early scientific activities aim to address key research needs

- NOAA released a CO_2 Removal Strategy Report highlighting NOAA's potential contributions
- Federal agencies investing in new grants aimed at evaluation
  - NOAA $30 million; ecosystem co-benefits and risks
  - Dept. of Energy, ARPA-E $45 million; sensing and validation



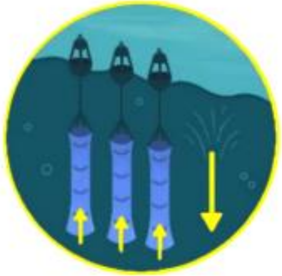
Goals of this talk

- Introduce marine Carbon Dioxide Removal (mCDR)
- Identify science needs
- Describe SCCWRP’s activities

There are 5 groups of mCDR technologies


Ocean Iron Fertilization

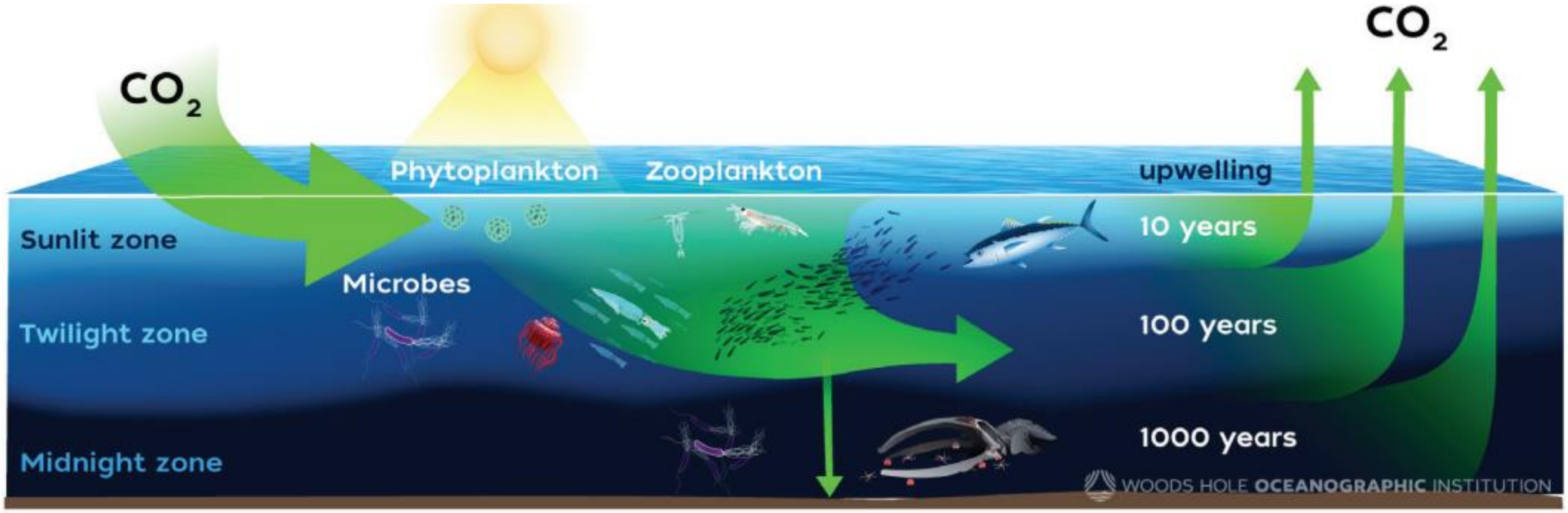

Alkalinity Enhancement


Artificial Upwelling


Electrochemistry

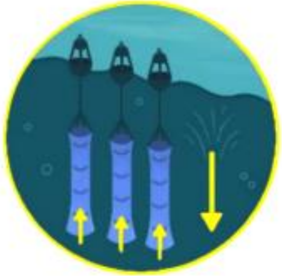

Seaweed Cultivation

The biological carbon pump is efficient at fixing carbon near the surface and redistributing that carbon into the deep



The first 3 groups of mCDR target the biological carbon pump

Nutrient Fertilization



Artificial Upwelling

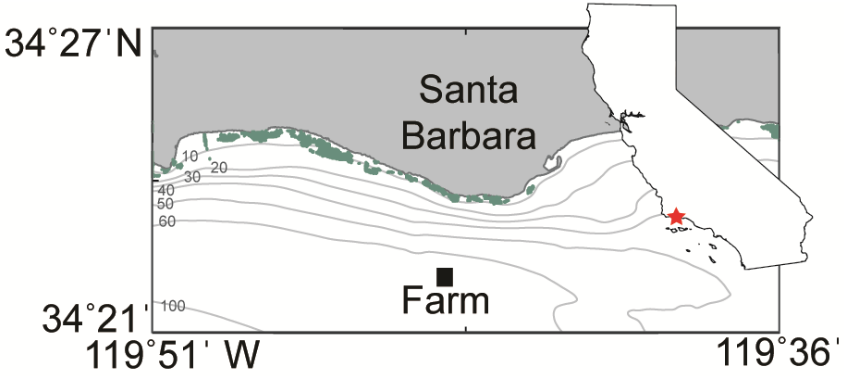
- Increase phytoplankton production with addition of limiting nutrients
- Enhance transfer of carbon to the deep sea
- These technologies likely to target oligotrophic regions of the ocean

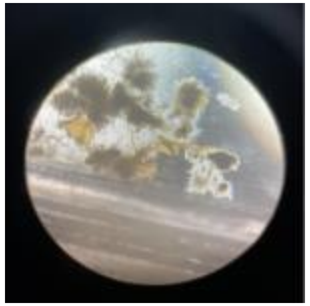
Seaweed Cultivation

- Targets macroalgae
- Sink biomass to deep sea

Southern California is already a test bed for seaweed farming

- Multiple DOE funded projects in SCB
- Pilot kelp farm off Santa Barbara
- Seed banks of giant kelp





Nuzhdin / AltaSeads

Javier Infante / Ocean Rainforest

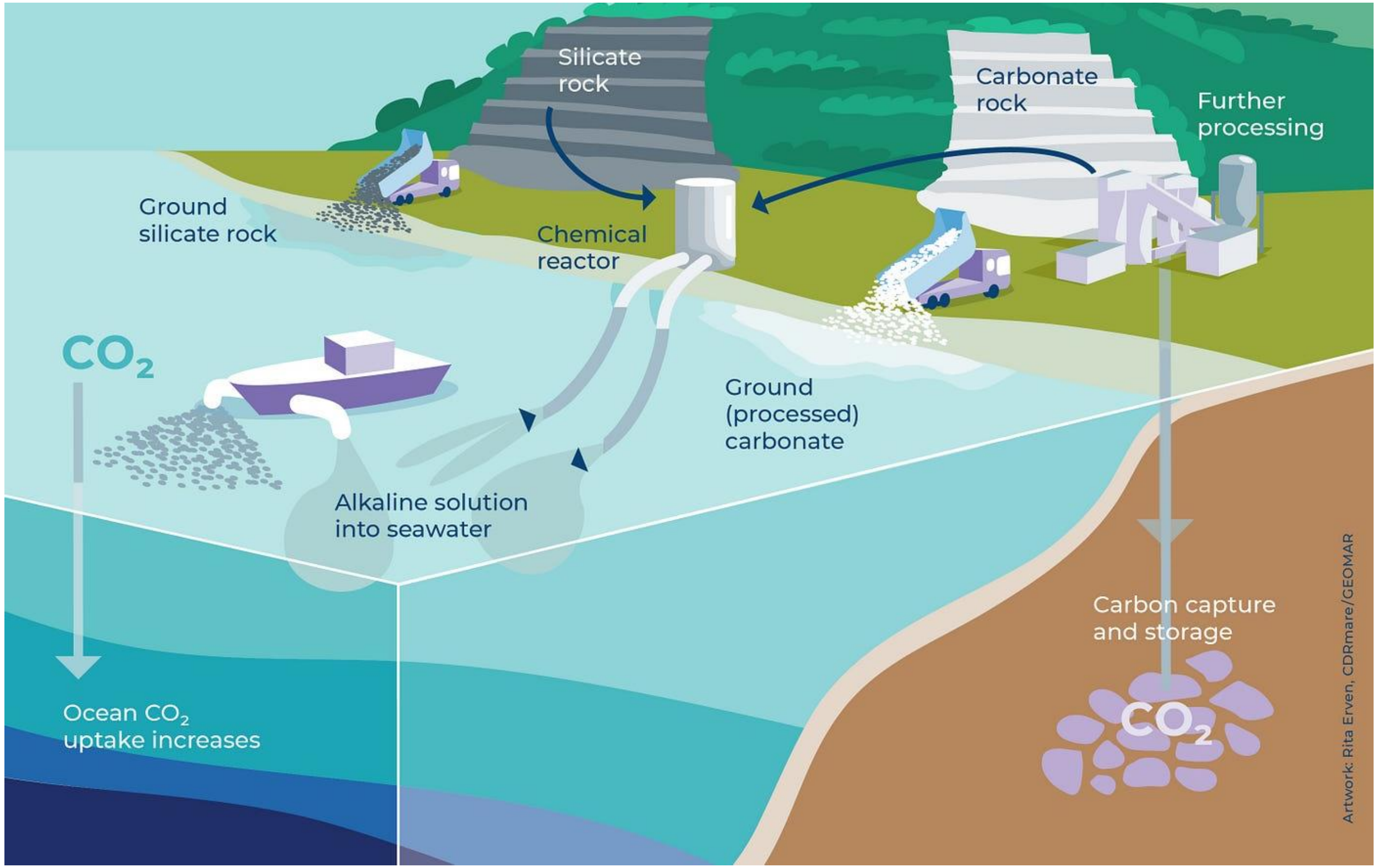
The other two mCDR groups target directed alteration of seawater chemistry

Alkalinity Enhancement

Electrochemistry

Alkalinity enhancement is achieved by adding large amounts of silicate or carbonate rock to the surface ocean

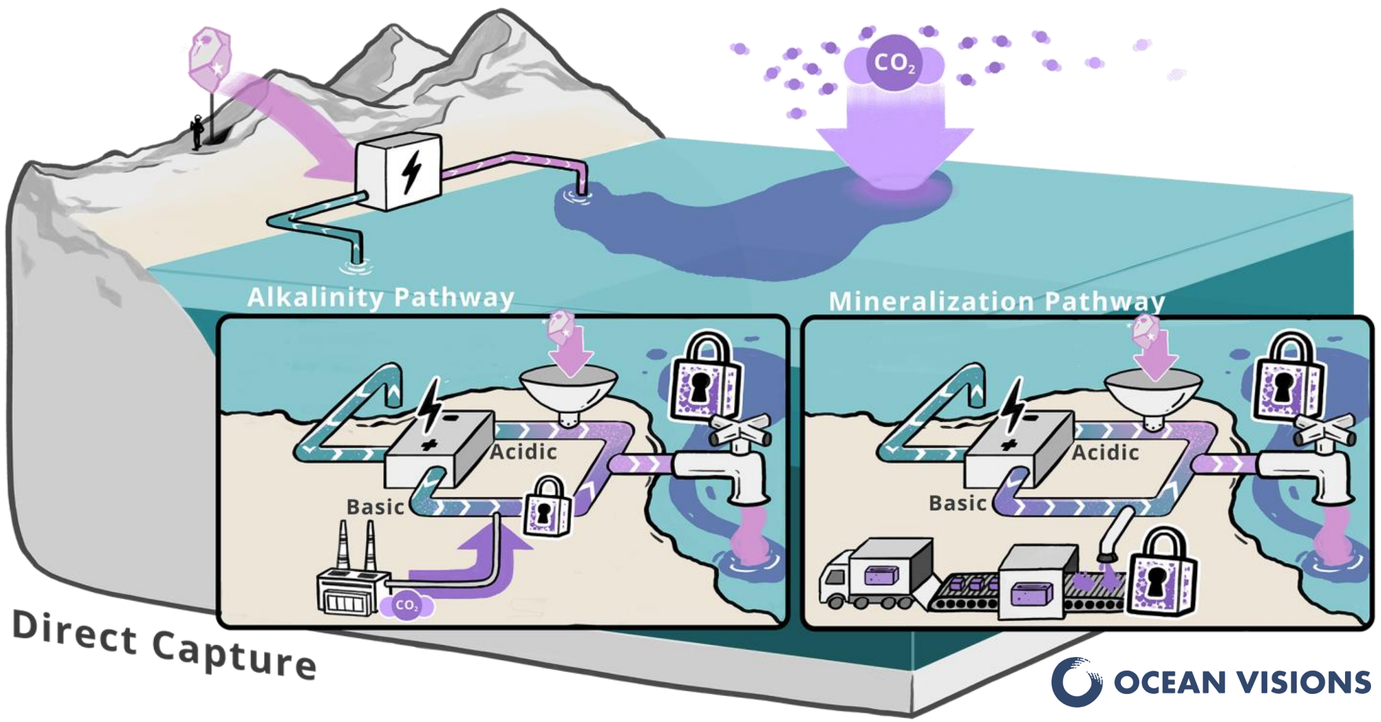
- This "locks" CO_2 into other forms of DIC (bicarbonate and carbonate)
- Promotes atmospheric CO_2 influx
- Leads to a temporary rise in pH; counteracting ocean acidification



Electrochemical approaches use electricity to either (a) extract CO_2 from seawater and/or (b) increase ocean alkalinity

<u>Acidic Stream</u>

- Degas CO_2 for storage, or
- Use to weather rocks and increase alkalinity



<u>Basic Stream</u>

- Used to absorb extra CO_2, or
- Precipitate minerals to store carbon as a solid

Pilot-scale projects of electrochemical technologies are underway in Southern California, and elsewhere.

Equatic

Gina Ferazzi / LA Times

CAPTURA

How much is pilot scale?

Scale	CO_2 Removed
Lab	Demonstrated
Pilot	**1 tonne CO_2**
Commercial	10^4 tonnes CO_2
Full	10^9 tonnes CO_2

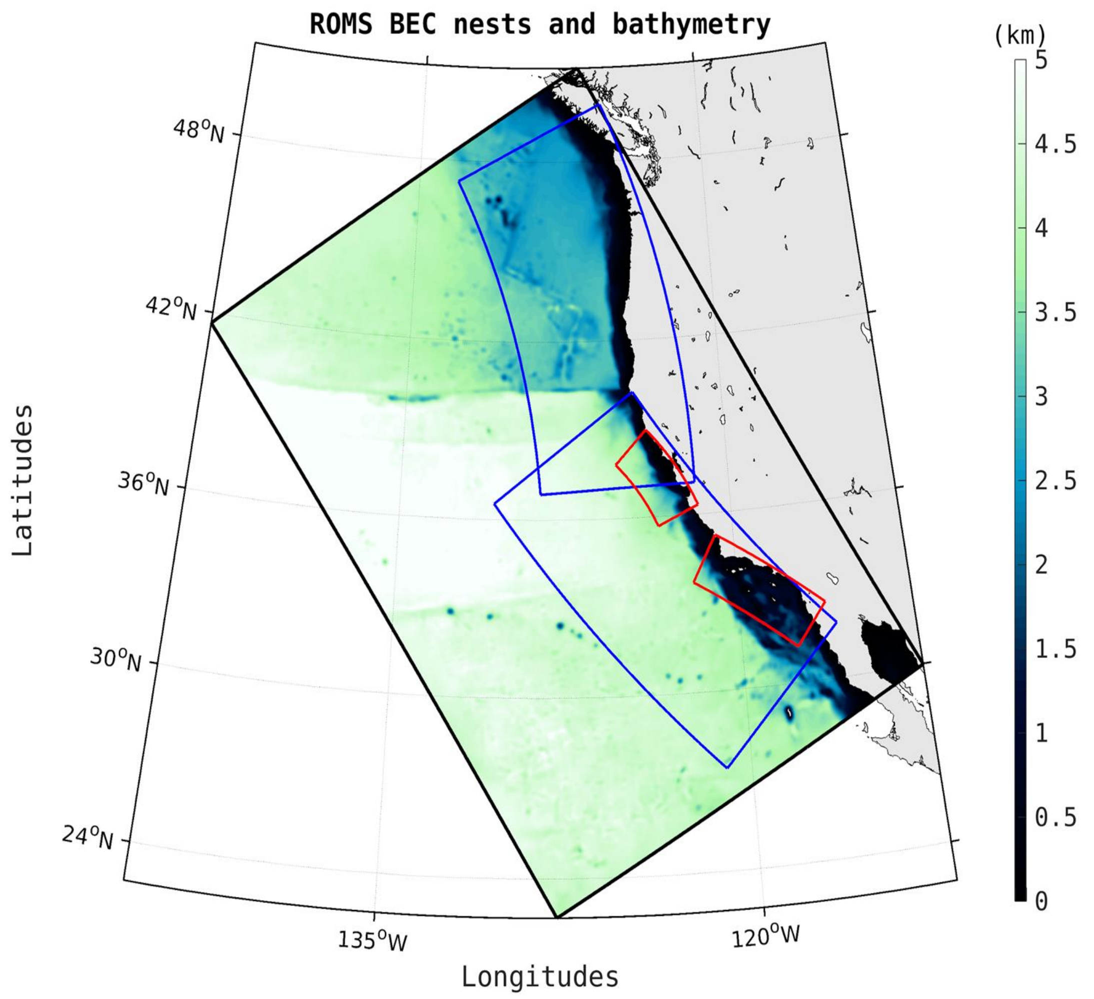
- Pilot-scale tests are operating under Vessel General Permit

SCCWRP is contributing to mCDR evaluation in three key areas

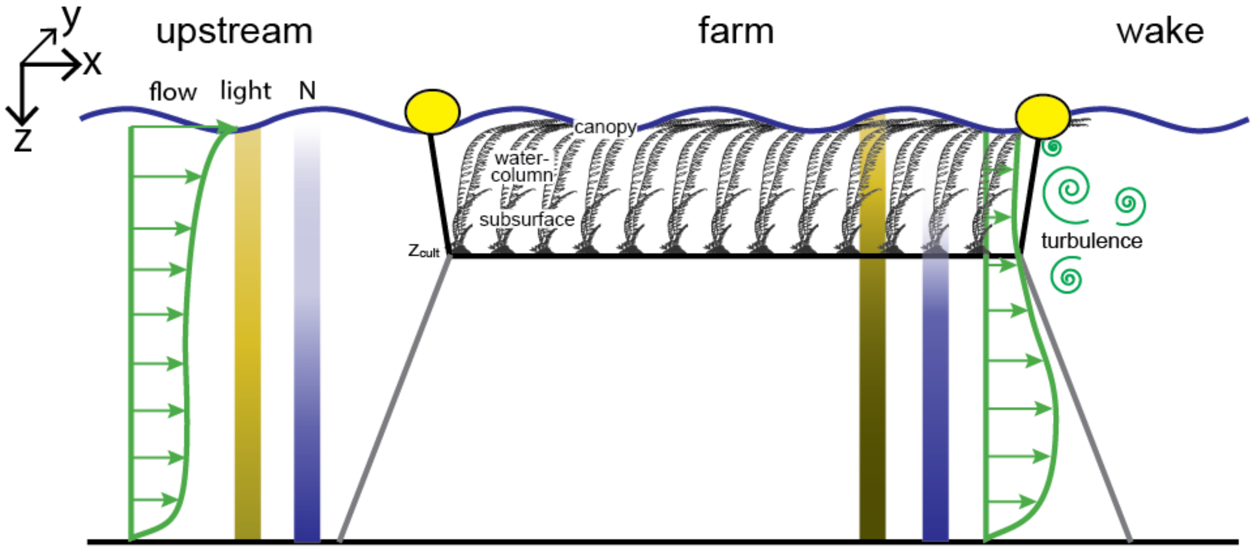
1. Pilot-scale evaluation
2. Regional-scale assessment
3. Unintended consequences

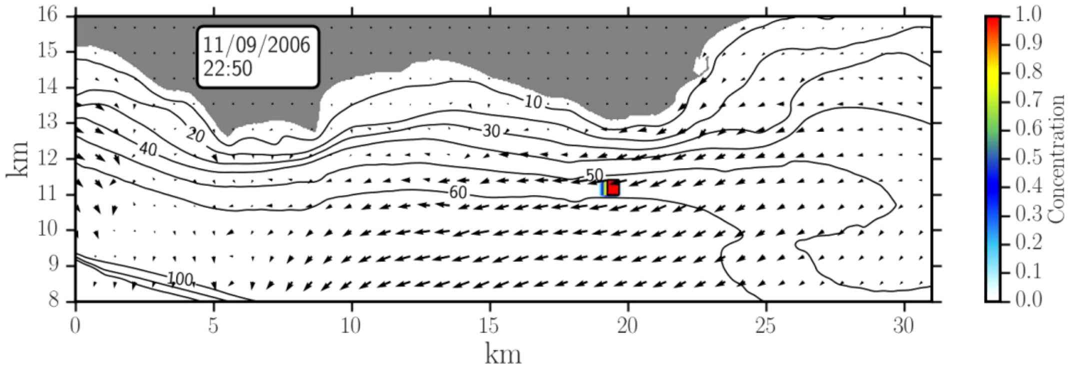
Our numerical ocean model is a key tool to evaluate the effectiveness of mCDR

- Existing observational assets are insufficient to capture the large scales over which CO_2 drawdown occurs
  - ➢ 100’s of kms; years
- ROMS-BEC allows us to assess the efficiency of the technology over required time and space scales



We have expanded our modeling capacities to represent different mCDR pathways within ROMS-BEC





MACMODS
MacroAlgae Cultivation MODeling System

Frieder et al. 2022 *Frontiers in Marine Science*

There are anticipated environmental risks

Seaweed Cultivation

Alkalinity Enhancement

Electrochemistry

- Disease; genetics
- Marine mammal entanglement
- Competition with phytoplankton
- Deep-sea changes

- Dissolution by-products
  - Possible negative impacts
  - Change composition of phytoplankton communities

- Mortality of marine life from intake pipes
- Effluent characteristics could limit phytoplankton growth
- Dissolution by-products

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phytoplankton

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  - Possible negative

phytoplankton communities

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growth

- Dissolution by-products

However, there is no framework to evaluate these risks

Engagement with and products for our member agencies

- A framework to balance the pros and cons of mCDR technologies
  - How efficient is the mCDR technology?
  - What are the environmental risk?

- An expanded toolkit of ocean solutions
  - Are there other options to reduce effects of eutrophication that are more cost effective than nutrient management?