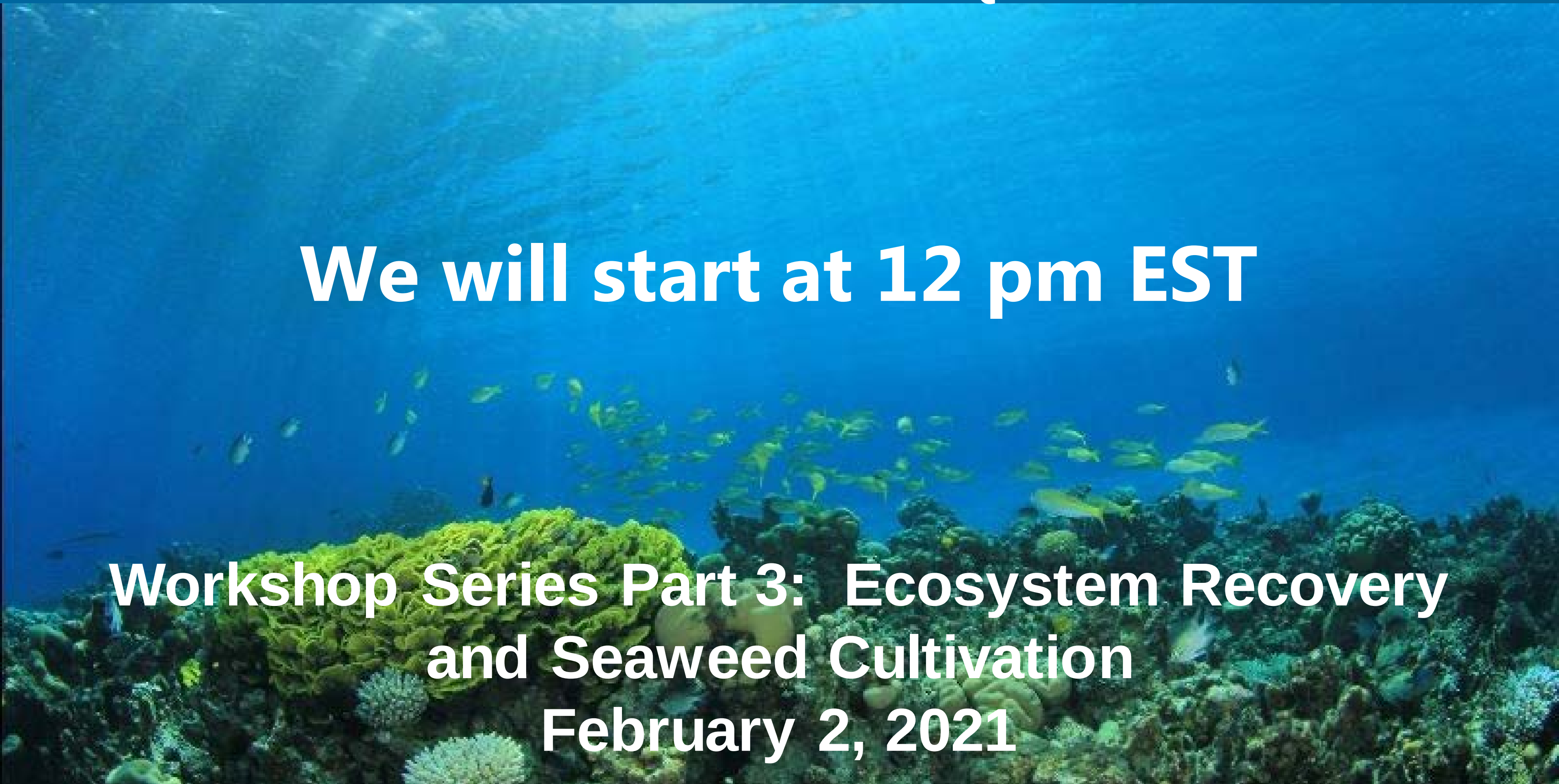
The National Academies of
SCIENCES · ENGINEERING · MEDICINE

A RESEARCH STRATEGY FOR OCEAN CARBON DIOXIDE REMOVAL AND SEQUESTRATION



We will start at 12 pm EST

Workshop Series Part 3: Ecosystem Recovery and Seaweed Cultivation
February 2, 2021

Virtual Logistics

- Keep mics and cameras on while speaking and while participating in a panel.
- Committee members and panelists, please use the raise hand function or submit questions through the chat
- If you are watching the webinar, submit questions or comment through Q&A
- Presentations and recording will be posted on our project website: https://www.nationalacademies.org/our-work/a-research-strategy-for-ocean-carbon-dioxide-removal-and-sequestration
- Questions or information about the study, contact Kelly Oskvig, koskvig@nas.edu

Background

- NASEM Consensus Study
- Sponsored by the ClimateWorks Foundation
- Exploring 6 Ocean-based CDR Strategies:
  - Identify the most urgent unanswered scientific and technical questions needed to: assess the benefits, risks, and sustainable scale potential CDR approaches
  - Define the essential components of a research and development program and specific steps that would be required to answer these questions;
  - Estimate the costs and potential environmental impacts of such a research and development program to the extent possible in the timeframe of the study.
  - Recommend ways to implement such a research and development program that could be used by public or private organizations.

Workshop Series

- **January 19, 2021** - Part 1: Setting the Stage
- **January 27, 2021** - Part 2: Technological and Natural Approaches to Ocean Alkalinity Enhancement and CO2 removal
- **February 2, 2021** - Part 3: Ecosystem Recovery and Seaweed Cultivation
- **February 25, 2021** - Part 4: Nutrient Fertilization and Artificial Upwelling and Downwelling

The Committee

Scott Doney (Chair)	University of Virginia
Ken Buesseler	Woods Hole Oceanographic Institution
Jane Flegal	William and Flora Hewlett Foundation
Debora Iglesias-Rodriguez	UC Santa Barbara
Kate Moran	Ocean Networks Canada
Andreas Oschlies	GEOMAR
Phil Renforth	Heriot-Watt University
Joe Roman	University of Vermont
Gaurav Sant	UC Los Angeles
David Siegel	UC Santa Barbara
Romany Webb	Columbia Law School
Angelicque White	University of Hawai'i

Agenda

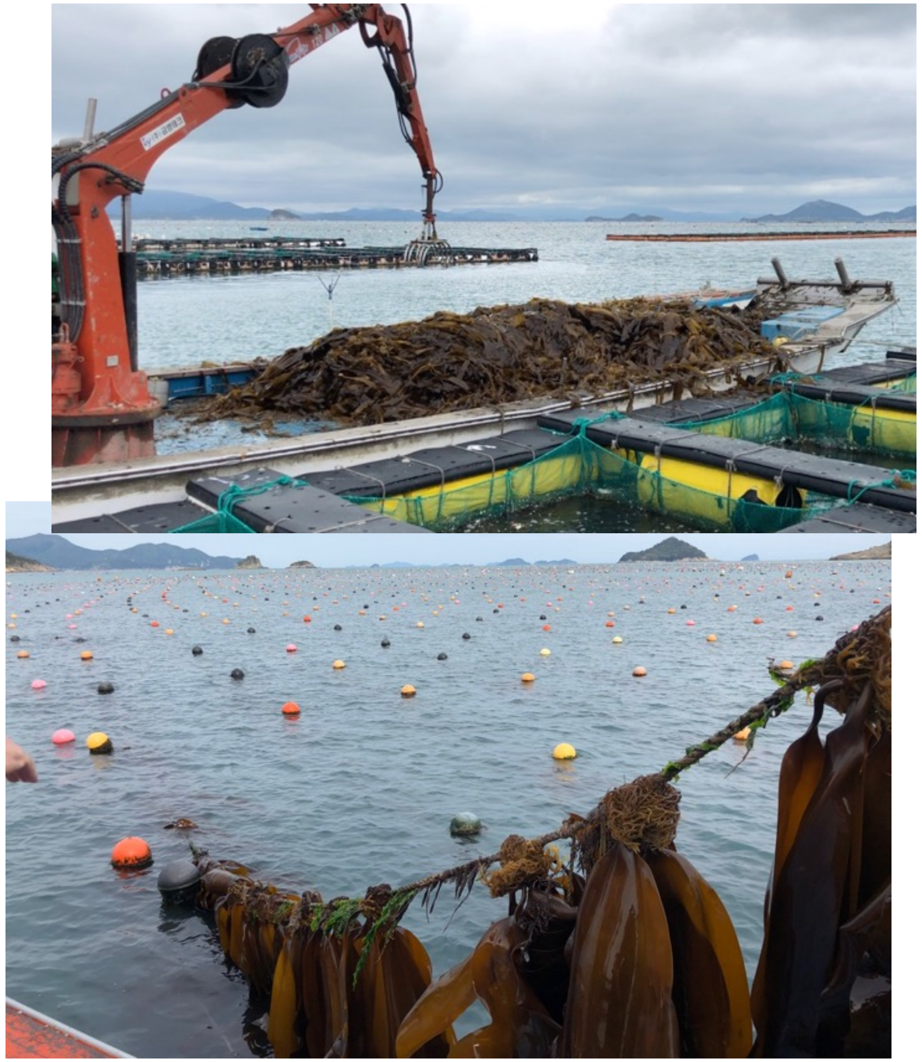
12:00pm	Welcome
12:05pm	Keynote: The Marine Ecosystem as a Climate Solution
12:45pm	Seaweed Cultivation: Opportunities and Challenges
2:15pm	BREAK
2:30pm	Ecosystem Recovery: Opportunities and Challenges
4:00pm	Adjourn

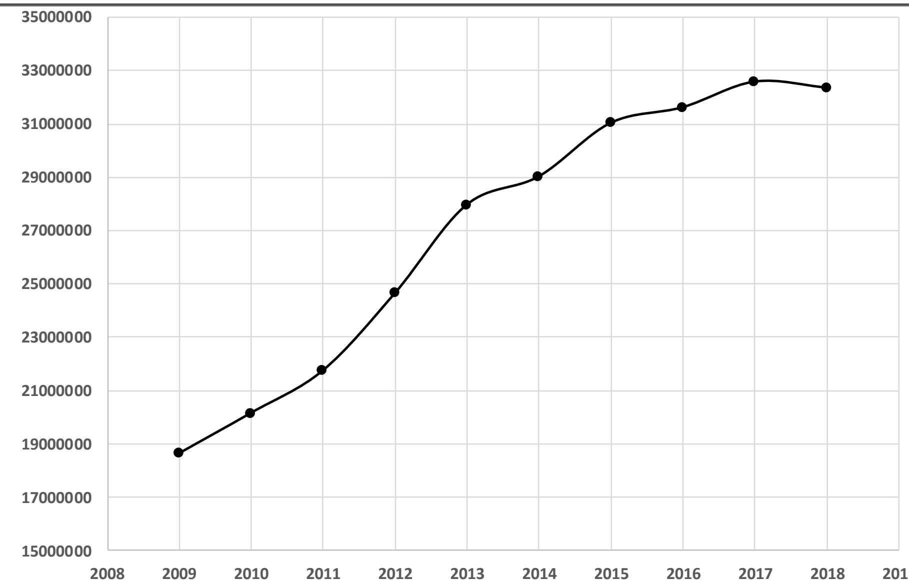
Scaling Macroalgae Cultivation for Energy and Climate

Marc von Keitz, Ph.D.
Program Director @ ARPA-E
marc.vonkeitz@hq.doe.gov

NASEM
February 2, 2021

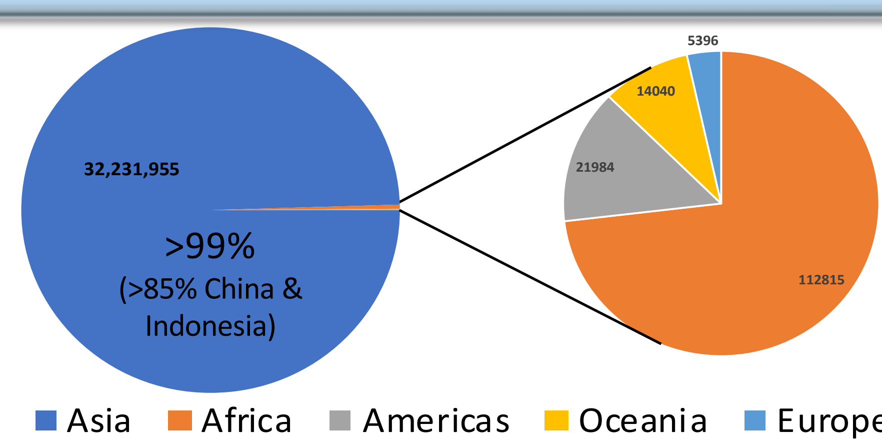
Global Production of Seaweed: 32.4 Million Wet Tons in 2018





Production nearly doubled over last 10 years

World Wide Aquatic Plant Production 2009-2018 (Wet Tons)[1]



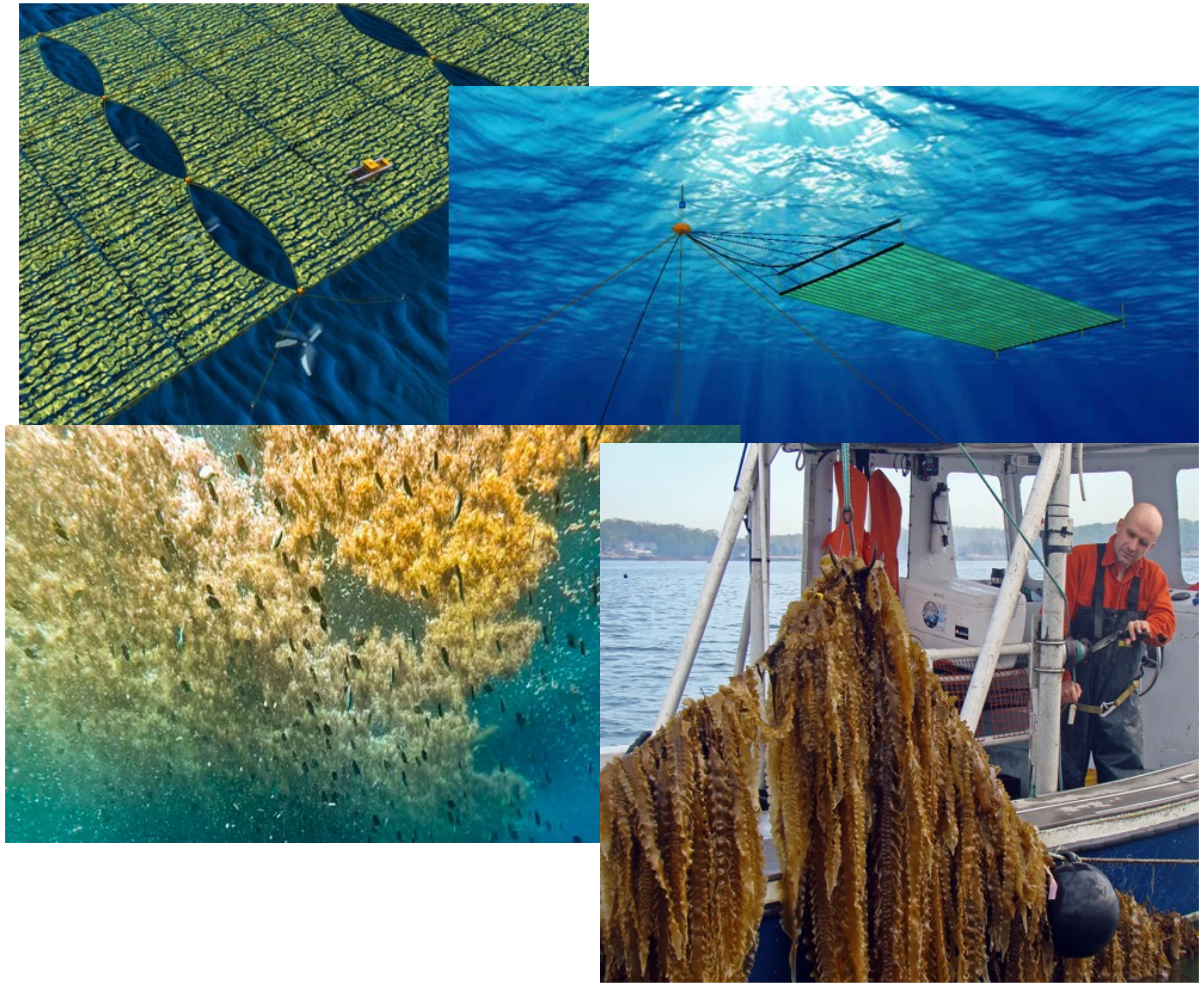
Today Asia dominates production

[1]Data taken from *2018 FAO Yearbook Fishery and Aquaculture Statistics: "http://www.fao.org/fishery/statistics/en"*

arpa·e CHANGING WHAT'S POSSIBLE

Marc von Keitz

What does it take to reach energy/climate scale?



- Move off-shore and survive/operate in open-ocean conditions
- Accessing "free" nutrients predictably and reliably
- Maximize biomass yield by optimizing productivity of individual plants and whole farm system
- Highly energy-efficient operation and harvesting through advanced automation & remote monitoring

Capturing 1 Giga Ton of CO_2 with Macroalgae

	Conservative	Medium	Optimistic
Dry weight yield (t/ha)	10	30	50
Carbon Content (% dry weight)	25%	27%	30%
CO_2 captured (t/t biomass)	0.92	0.99	1.10
CO_2 captured per year (t/ha)	**9**	**30**	**55**
Area to capture 1 Gt CO_2 per year (km^2)	**1,091,000**	**337,000**	**182,000**
Cost of biomass production (US$/t dry weight)	200	130	80*
Cost of capturing 1 t of CO_2 (US$)	**218**	**131**	**73**

Numbers presented in this table, while in the right ball-park, are primarily for illustrative purposes

* ARPA-E MARINER cost target

1 Ton of Macroalgae (dry) ≅ 1 Ton of CO_2 captured

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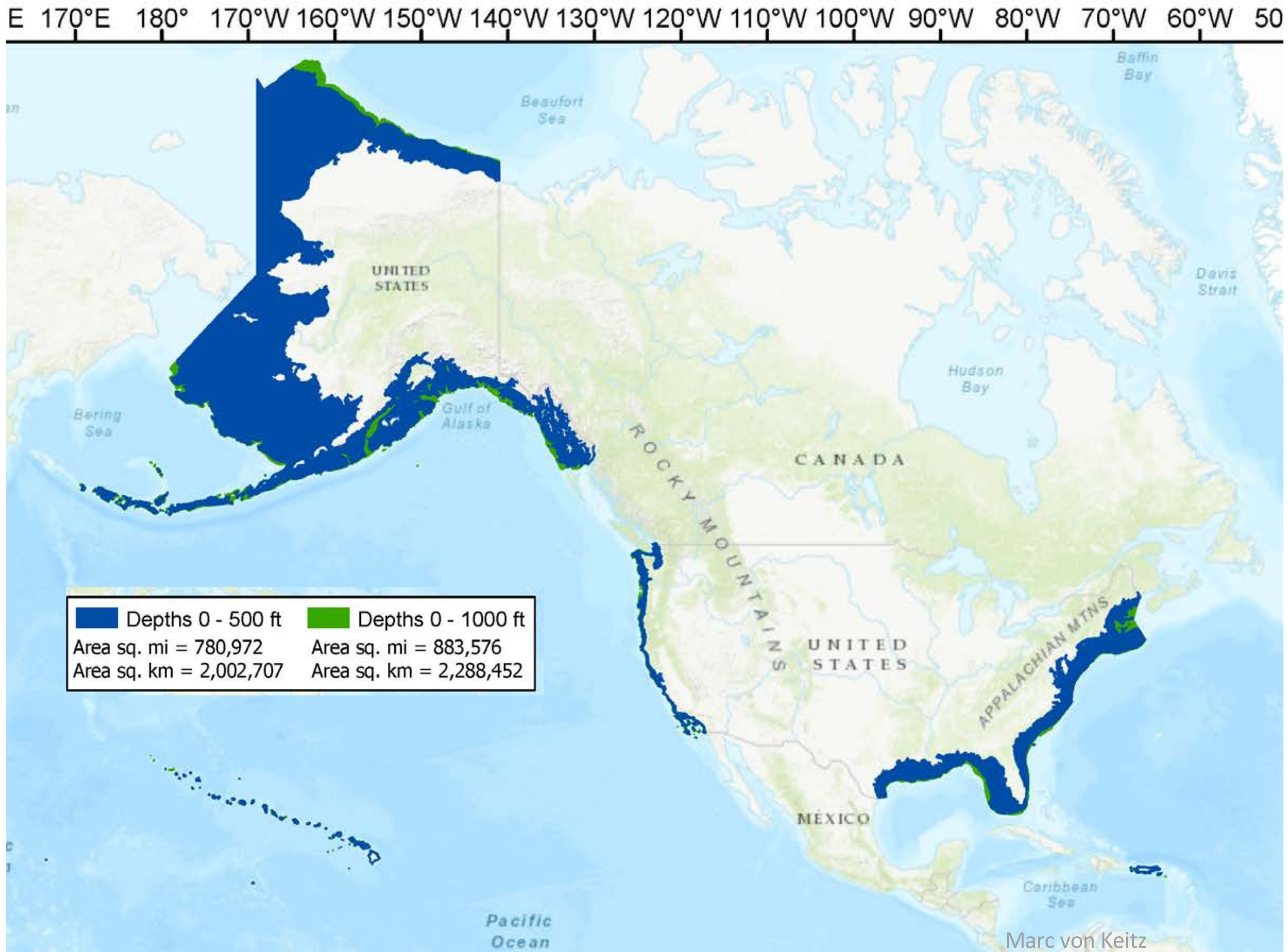
Marc von Keitz

How far off-shore do we have to go?

	0 - 1000 ft		
Region	**Area (mi²)**	**Area (km²)**	**% of US EEZ**
Alaska	554,365	1,435,799	11.8%
Caribbean	3,210	8,314	0.1%
East Coast	150,945	390,946	3.2%
Gulf of Mexico	136,687	354,018	2.9%
Pacific Islands	9,953	25,778	0.2%
West Coast	28,416	73,597	0.6%
Total	**883,576**	**2,288,452**	**18.8%**

ARPA-E has been funding NOAA efforts on Marine Spatial Analysis and Planning for macroalgae via an Inter-Agency Agreement



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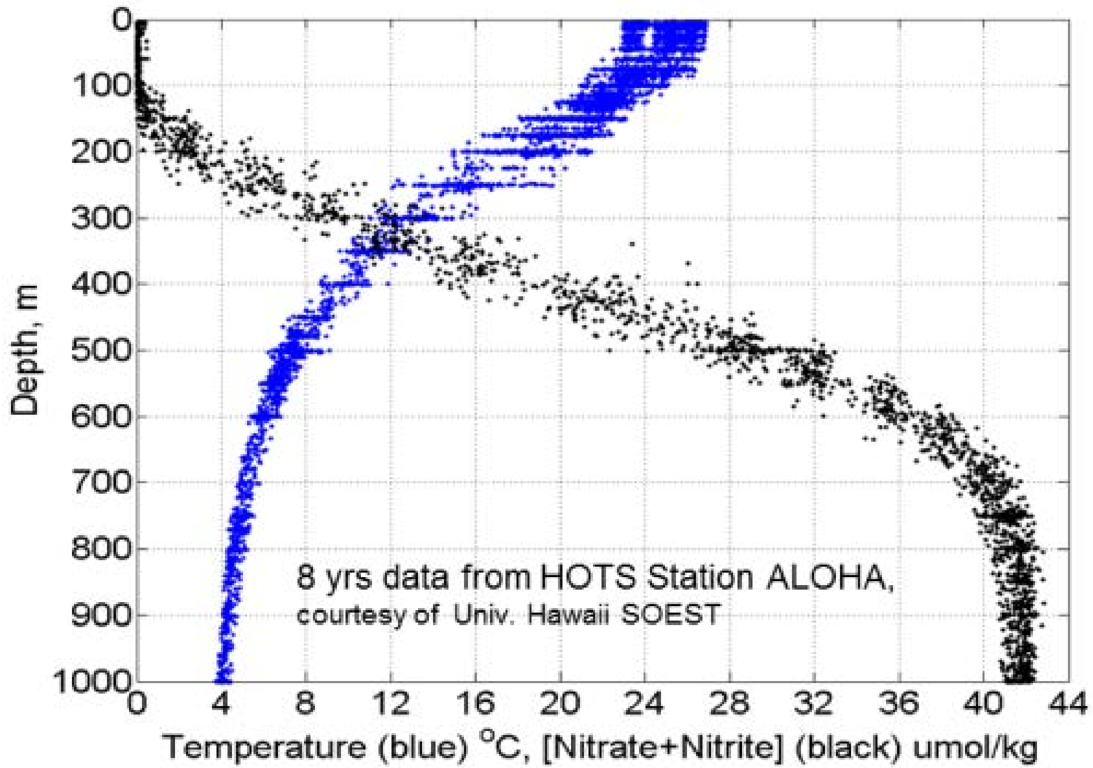
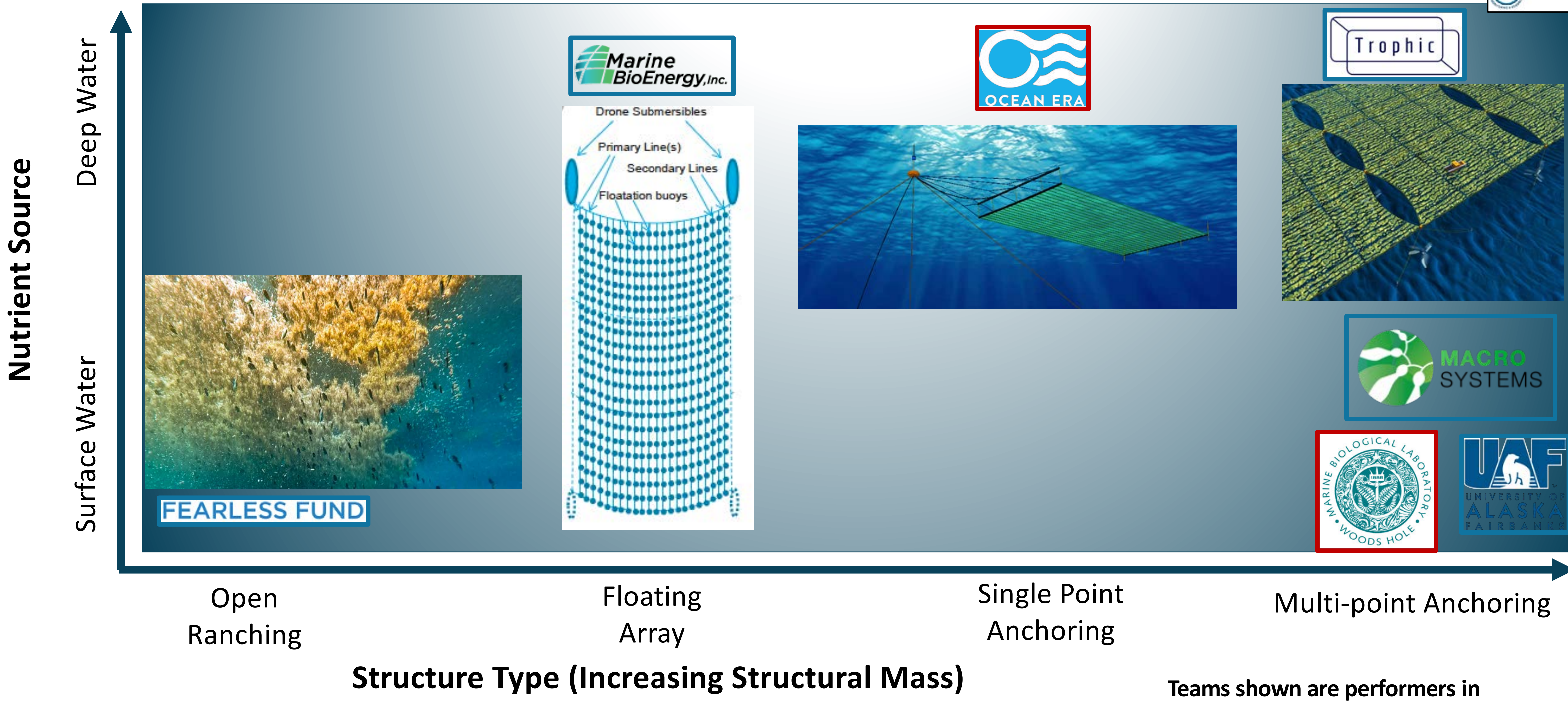
Access to Nutrients

In many places the surface waters **do not contain enough nutrients** to support macroalgae cultivation



- Natural Upwelling
- Artificial Upwelling
- Diving to Nutrients

Diversity of Aquaculture Approaches



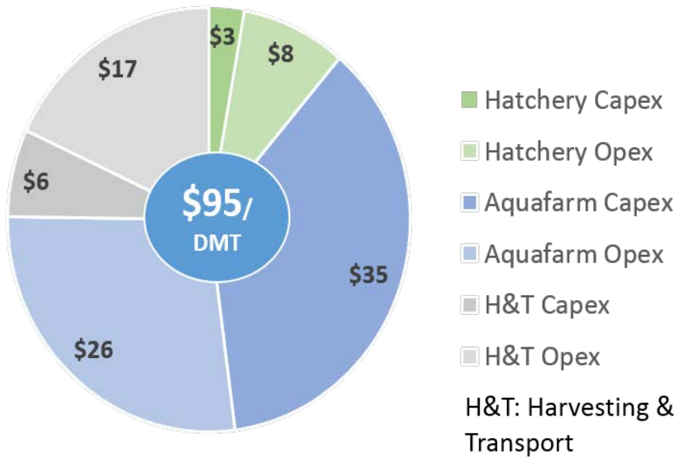
Red Algae

Brown Algae

Teams shown are performers in ARPA-E MARINER program

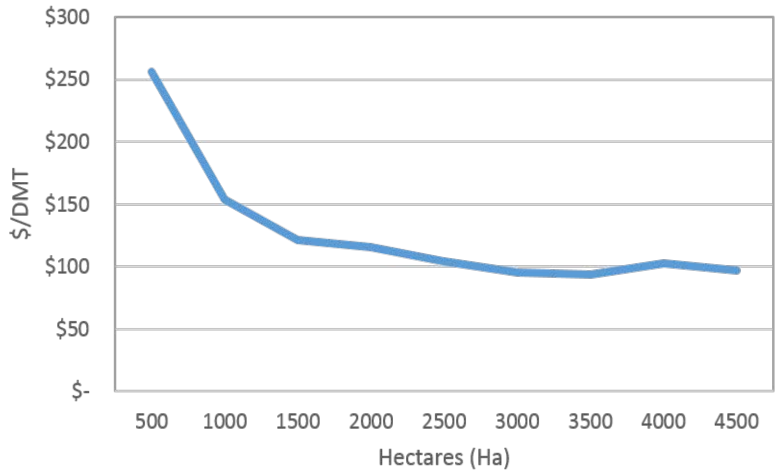
Yield, Scale, Farm CapEx are Key Cost Drivers

A.

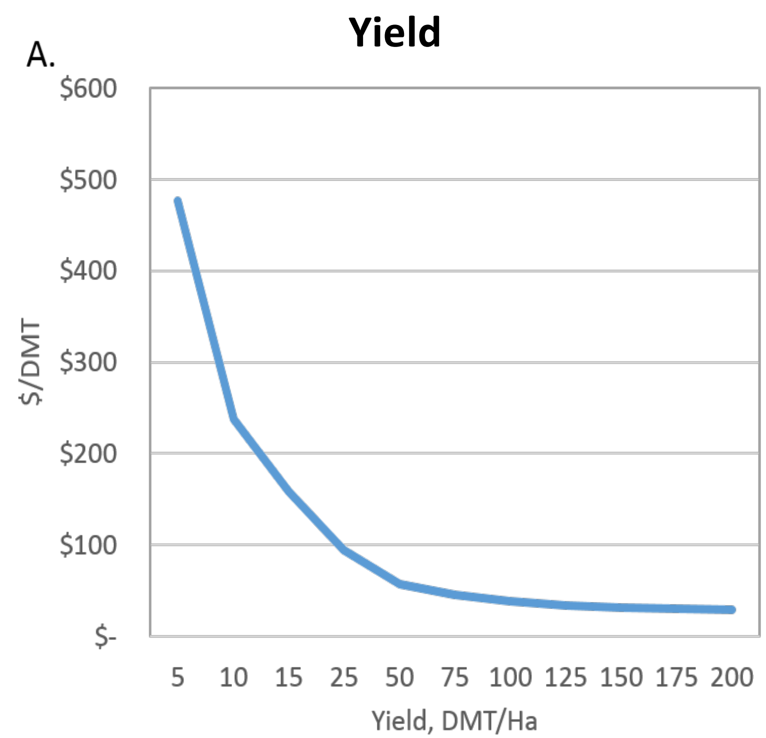


Scale

C.



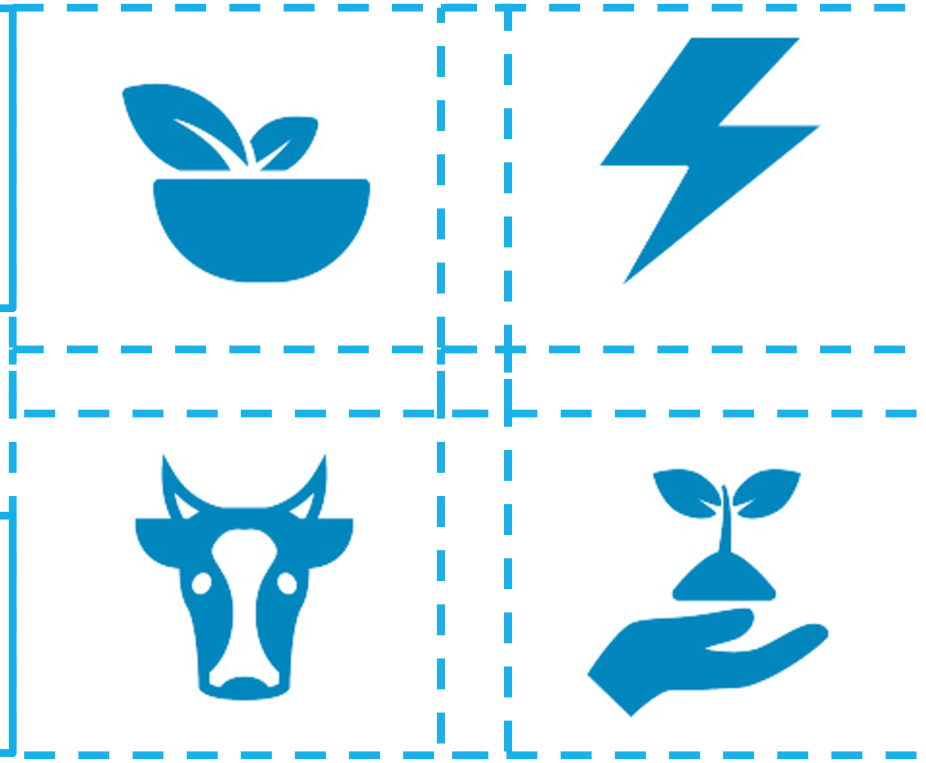
A.



Results of internal ARPA-E TEA
(2016, pre-MARINER FOA)

Macroalgae Pathways to Energy & Climate Benefits

Human
- Whole foods*
- Nutraceuticals
- Proteins*
- Hydrocolloids



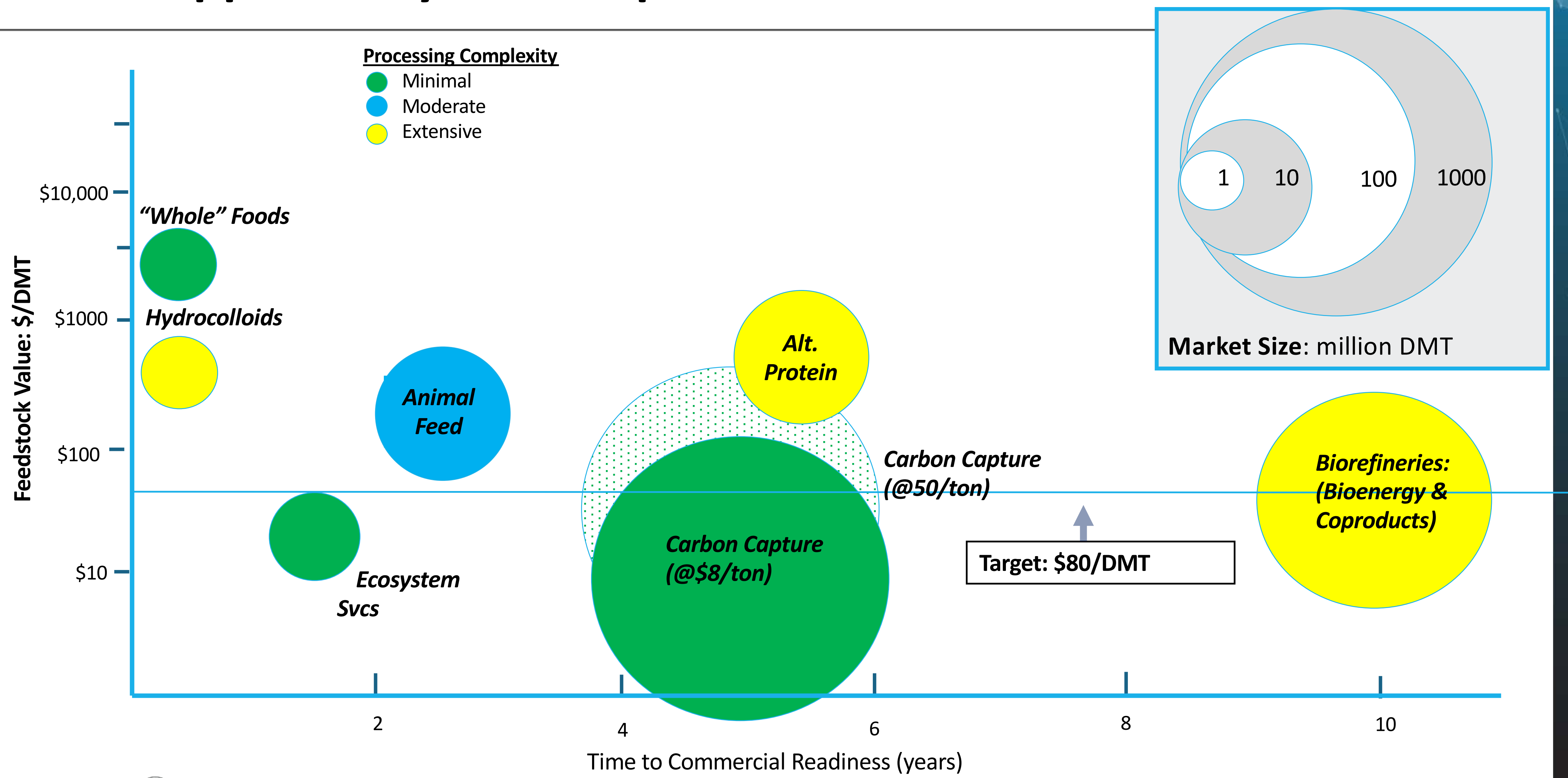
Energy and Industrial Products
- Biogas via anaerobic digestion*
- Biofuel via HTL or fermentation
- Chemicals and Intermediates

Animal Health & Nutrition*
- Ruminants (methane mitigation)
- Monogastrics

Ecosystem Services
- Nutrient reuptake
- Local deacidifcation
- Carbon sequestration & storage
- Fertilizers**

*** Potential to free up terrestrial agricultural land, better suited to longer-term carbon sequestration**
****Potential to replace Haber-Bosch Ammonia**
HTL: Hydrothermal liquefaction

Market Opportunity Landscape for Seaweed Biomass



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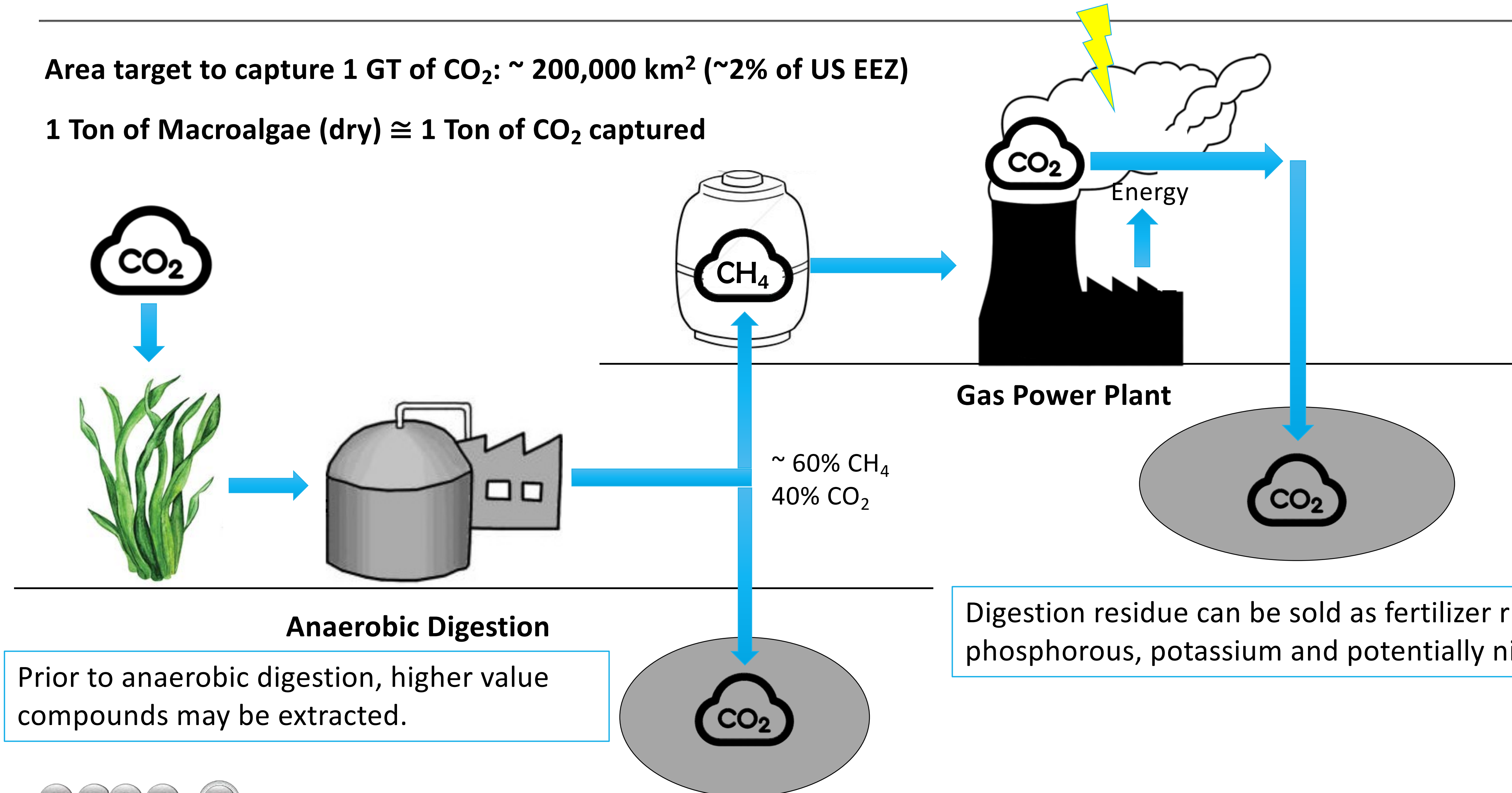
Macroalgae: From CO_2 Capture to Sequestration

- Cultivation-associated carbon sequestration
- Deep ocean sinking of macroalgae
- **BECCS**
- Conversion into chemicals used in durable goods

BECCS via a Macroalgae Biorefinery

Area target to capture 1 GT of CO_2: ~ 200,000 km^2 (~2% of US EEZ)

1 Ton of Macroalgae (dry) ≅ 1 Ton of CO_2 captured



Digestion residue can be sold as fertilizer rich in phosphorous, potassium and potentially nitrogen

Prior to anaerobic digestion, higher value compounds may be extracted.

Potential of methane and nitrogen from 1 GT of CO_2 captured by seaweed?

- **Calculation Assumptions:**
  - 910,000,000 dry metric tons of seaweed per year*
  - Theoretical max. Methane potential: ~200 kg/dry MT**
  - Nitrogen Content: 2-4% in dry matter

- **Results:**
  - Methane: <182 million MT/yr (~8.5 Quads)**
  - Nitrogen: 18.2-36.4 million MT nitrogen

Annual US Fertilizer Consumption in Million Metric Tons

Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)	Total
11.8	3.9	4.3	20.0

*assumes 30% C in dry matter ** rough estimate (assumes 30% ash in dry matter), theoretical maximum, current experimental results are significantly lower

Challenges to Address for Scaling Success:

Scientific /Technical Uncertainties:

- **Validating farm technology performance and cost-effectiveness in off-shore environment**
- **Quantifying and validating long term carbon outcomes**
- **Development of processing methods optimized for marine biomass**

Achieving Economies of Scale:

- **Scalability within supply chain:** cultivation, harvesting, transport, processing
- **Marketplace stepping-stones** that can sustain a growing industry
- **Attracting major investors / Corporate partners**

Regulatory Hurdles:

- **Permitting** for large-scale, off-shore operations: governed by multiple independent regulatory bodies requiring substantial due diligence.
  – Need "Tools for Rules"

Social License:

- **Gaining community acceptance**
- **Transparency in communicating and mitigating risks**
  – **Unintended environmental consequences**
  (e.g. invasive species, marine mammal entanglement, nutrient competition, aesthetic impacts)

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What is the minimum seaweed farm size
to demonstrate credible energy/climate impact ?
Marc von Keitz

Thank You!

Growing a Community to Spur Innovation

Marc von Keitz

Oceans, Seafood, and Aquaculture Investor Consortium

Energy products from macroalgae

Product	Processing Technology	Year implemented or demonstrated
Acetone	Maceration in digesters	1917
Methane/biogas	Anaerobic digestion	1970’s
Ethanol	Engineered *E. coli* ethanologen microbe	2011
HTL liquid/bio-oil	Hydrothermal liquefaction	2012

Digesters at Hercules Chemical Company in Chula Vista, CA

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University of California Santa Barbara

Interdepartmental Graduate Program in Marine Science

EEMB UC Santa Barbara

Environmental Studies
For Our Shared Future
UC Santa Barbara

Conservation Aquaculture Research Team

Seaweed aquaculture in a changing climate

Halley E. Froehlich
Assistant Professor
University of California, Santa Barbara

Froehlich Lab

Nation Academy of SEM
Ocean-based Carbon Dioxide Opportunities and Challenges
February 2, 2021

Climate change is a threat to and caused by our food system

CLIMATE CHANGE STRESSORS

AGRICULTURE

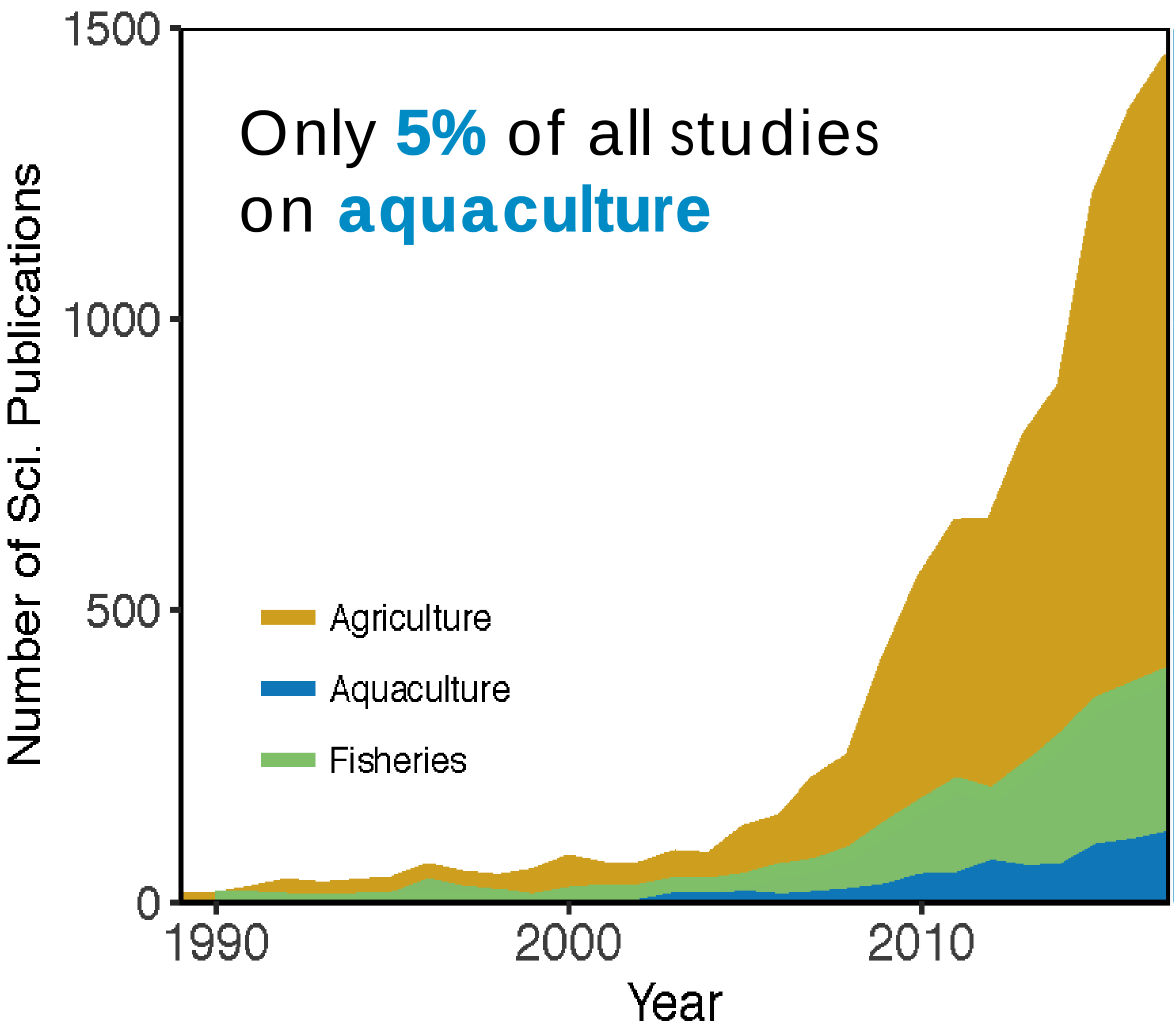
FISHERIES

AQUACULTURE

GHG Emissions

~20-25% of global emissions

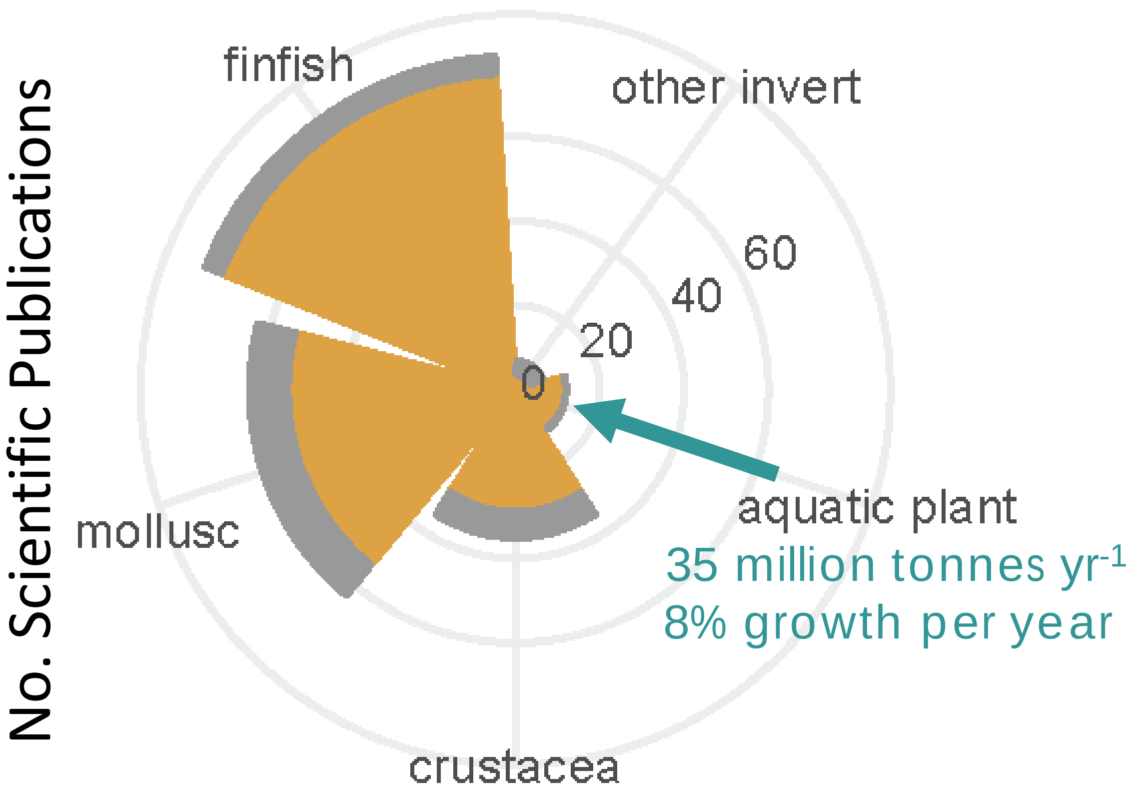
Aquaculture is half of seafood production, but the climate science lags behind



Froehlich et al. (in prep)

What do we know about aquaculture and climate change solutions?

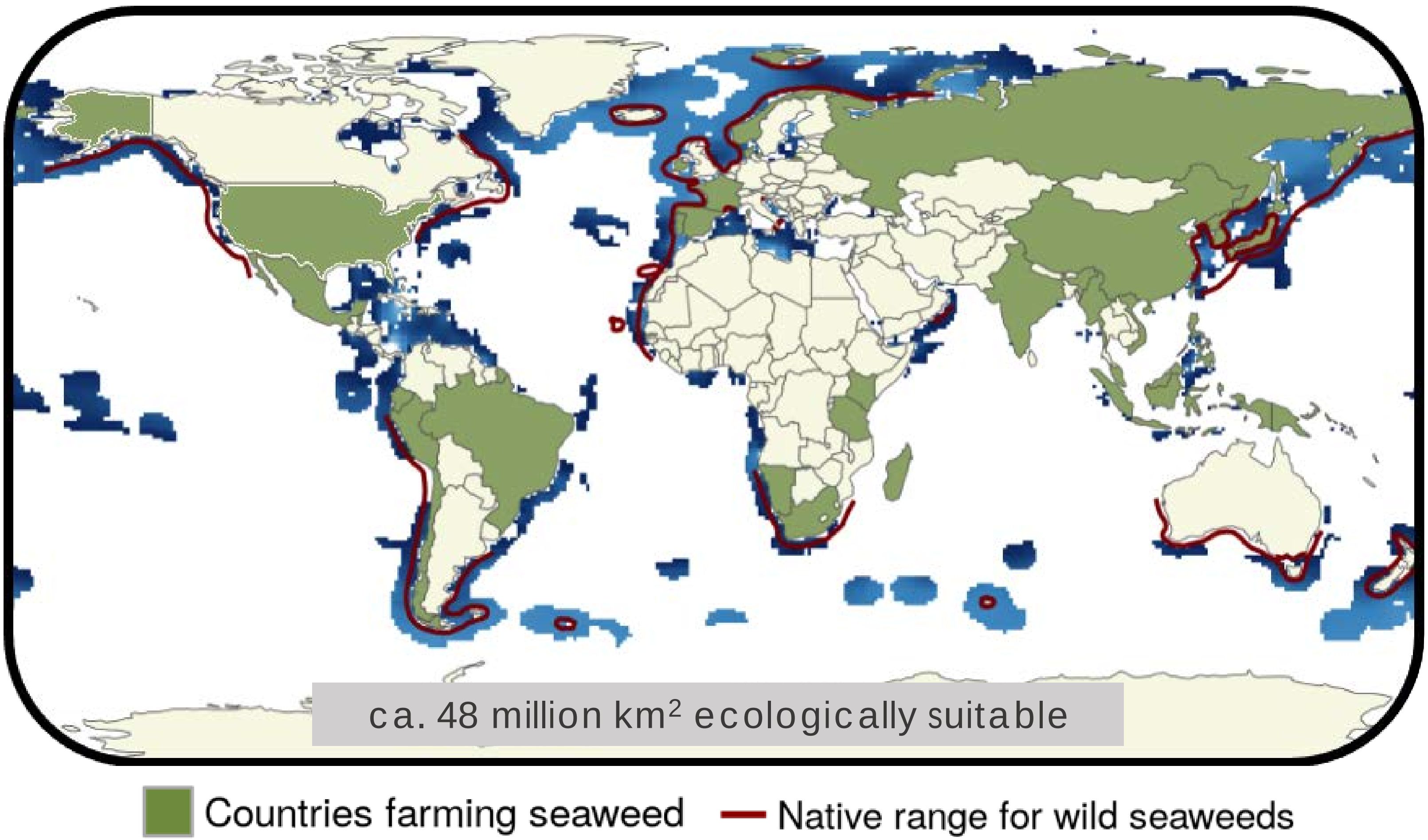
Very few scientific studies on farmed seaweeds & climate change



N = 555 scientific publications

Froehlich et al. (in prep)

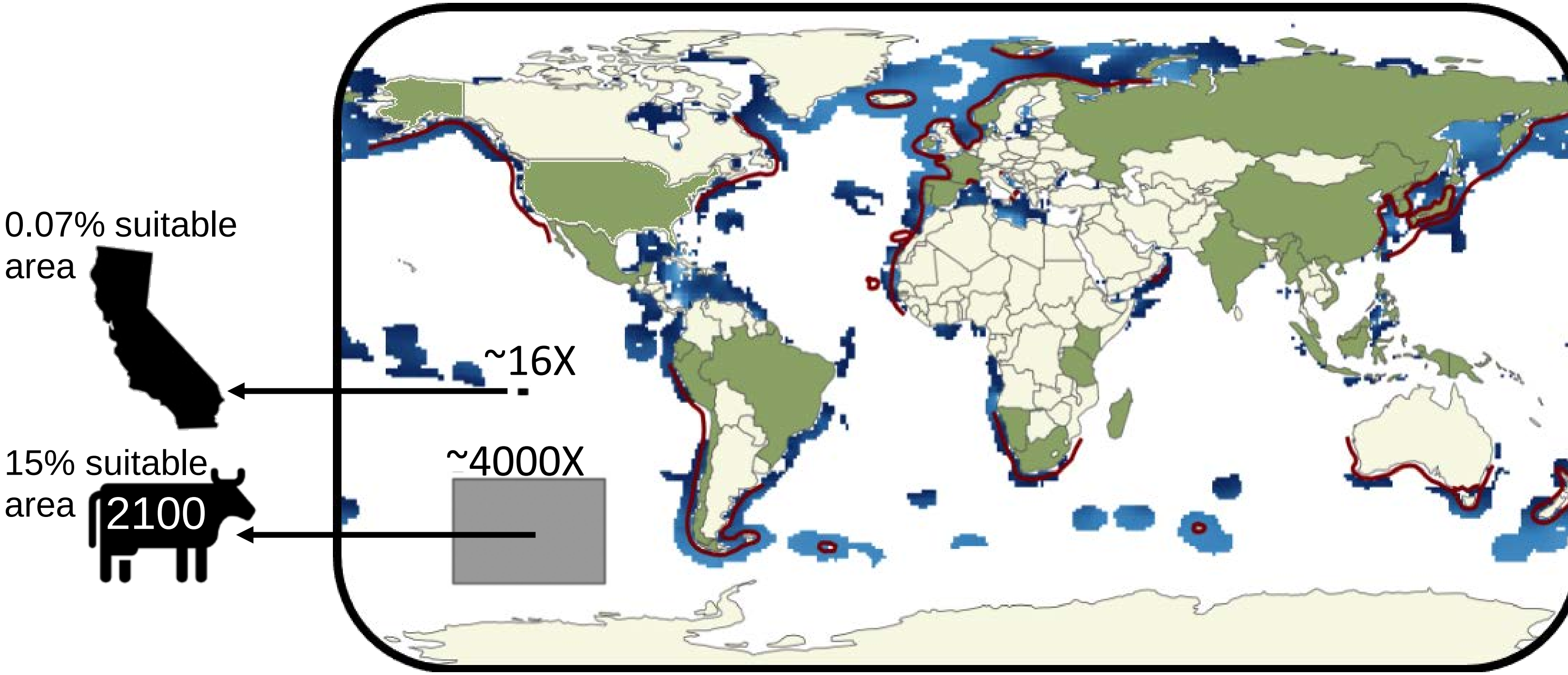
Map & model seaweed offsetting via facilitated deep sea sequestration



N = 33 species/groups

Froehlich et al (2019) Current Biology

Challenges of scale in addressing global agriculture emissions

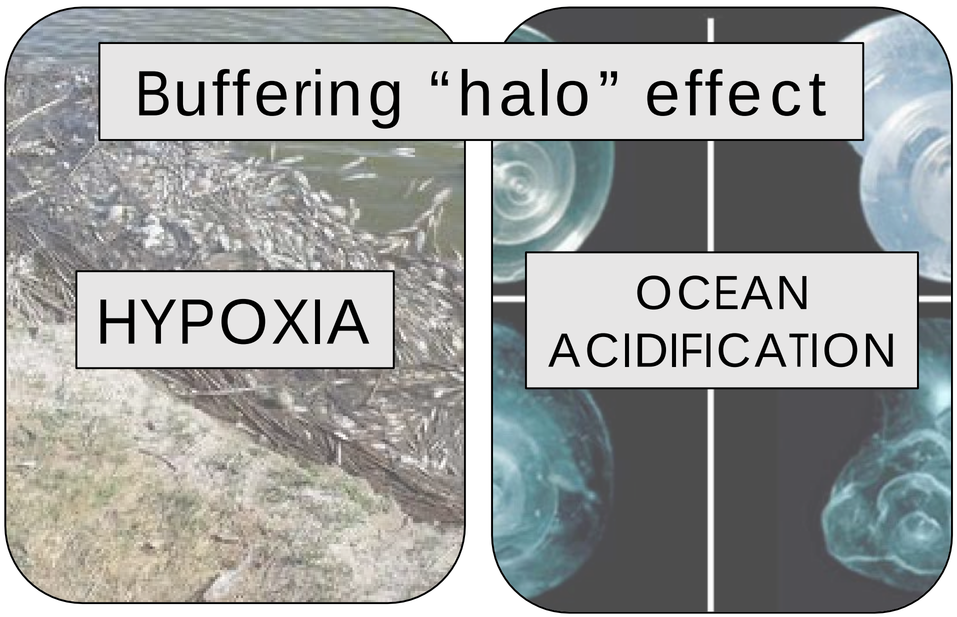


- Very expensive (median = \$543 per tonne of CO_2)
    - Terrestrial offsetting: \$33–\$384 per tonne of CO_2
- Genetic research needed
- Technology to facilitate sinking not used
- Seaweed policy to support growth very rare
- Not part of carbon market

Froehlich et al (2019) Current Biology

But, carbon neutrality & other "charismatic" co-benefit potential for the **aquaculture industry**

14-25% of standing farmed seaweed could offset global aquaculture industry emissions

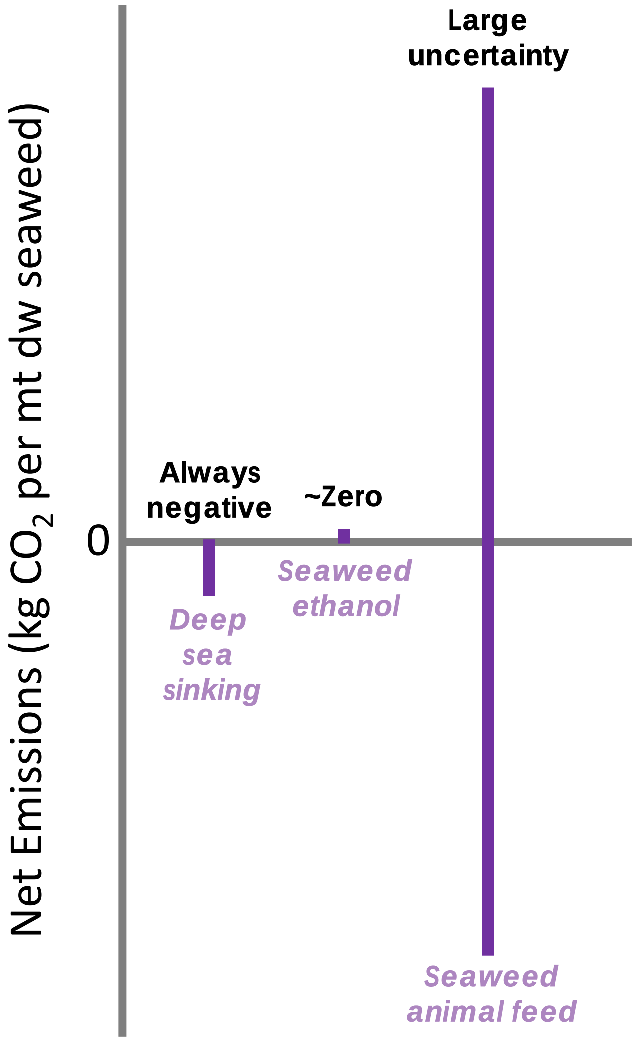


Local scales
moderate-high certainty

Local scales
low certainty

Froehlich et al (2019) Current Biology

Comparing life cycle potential of seaweed offsetting



Deep sea sinking: longer time scales

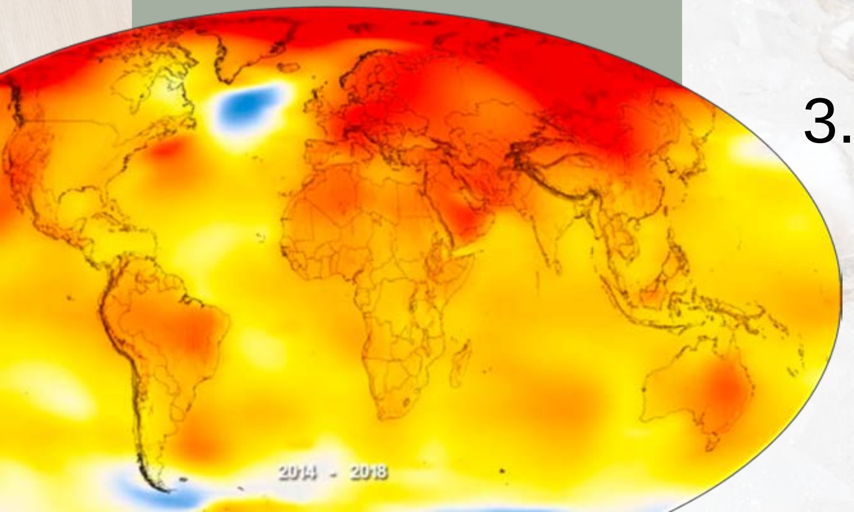
Ethanol: Better than corn?

Animal feed: reduce methane

Gaines, Bradley et al (in prep)

What does the future hold?

1. Seaweed aquaculture is growing fast, but scaling for carbon capture is a new frontier
2. Seaweed is not a “silver bullet” solution, but benefits from integrating seaweed into aquaculture shows more promise
3. Policies that include seaweeds that create incentive & reduce cost for the aquaculture industry



UCSB

Zegar Family Foundation

Thank you

EEMB
UC SANTA BARBARA

Conservation Aquaculture Research Team

NCEAS

https://froehlichlab.eemb.ucsb.edu/

Froehlich Lab

Environmental Studies
FOR OUR SHARED FUTURE
UC SANTA BARBARA

hefroehlich@ucsb.edu

@DocFroehlich

Scaling Open Ocean Seaweed Cultivation

Olavur Gergersen
CEO Ocean Rainforest

Presented at

National Academy of Science, Engineering and Medicine:
Workshop on Ocean-based CDR Opportunities and Challenges Part 3: Ecosystem Recovery & Seaweed Cultivation
February 2, 2021

OCEAN RAINFOREST

Business Model

Potential cultivation sites

Fresh biomass (uptake of CO_2)

Production processes

Market segments

Healthy & tasty food

Functional feed (reducing CH_4)

Food ingredients, bioplastic

OCEAN RAINFOREST

Challenges with scaling up offshore cultivation

DE GRUYTER Botanica Marina 2020; 63(4): 341–353

Review

Urd Grandorf Bak*, Ólavur Gregersen and Javier Infante

Technical challenges for offshore cultivation of kelp species: lessons learned and future directions

https://doi.org/10.1515/bot-2019-0005
Received January 11, 2019; accepted June 2, 2020; published online July 29, 2020

Keywords: economy; large-scale; macroalgae; open-ocean; productivity; seaweed farming.

Technical viability (survivability)

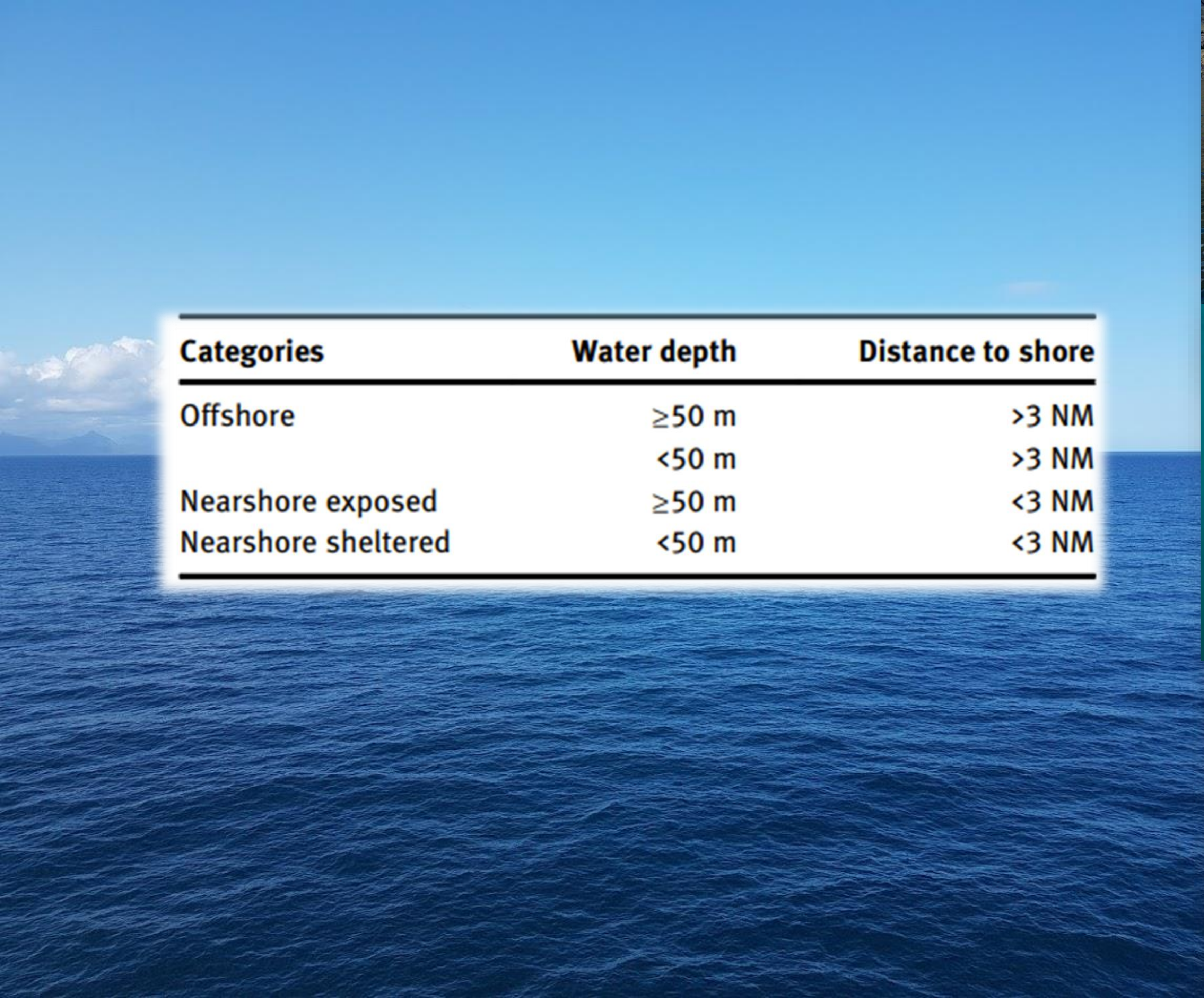
Cost of installation and operation (profitability)

Aquaculture output (productivity)

Sustainability

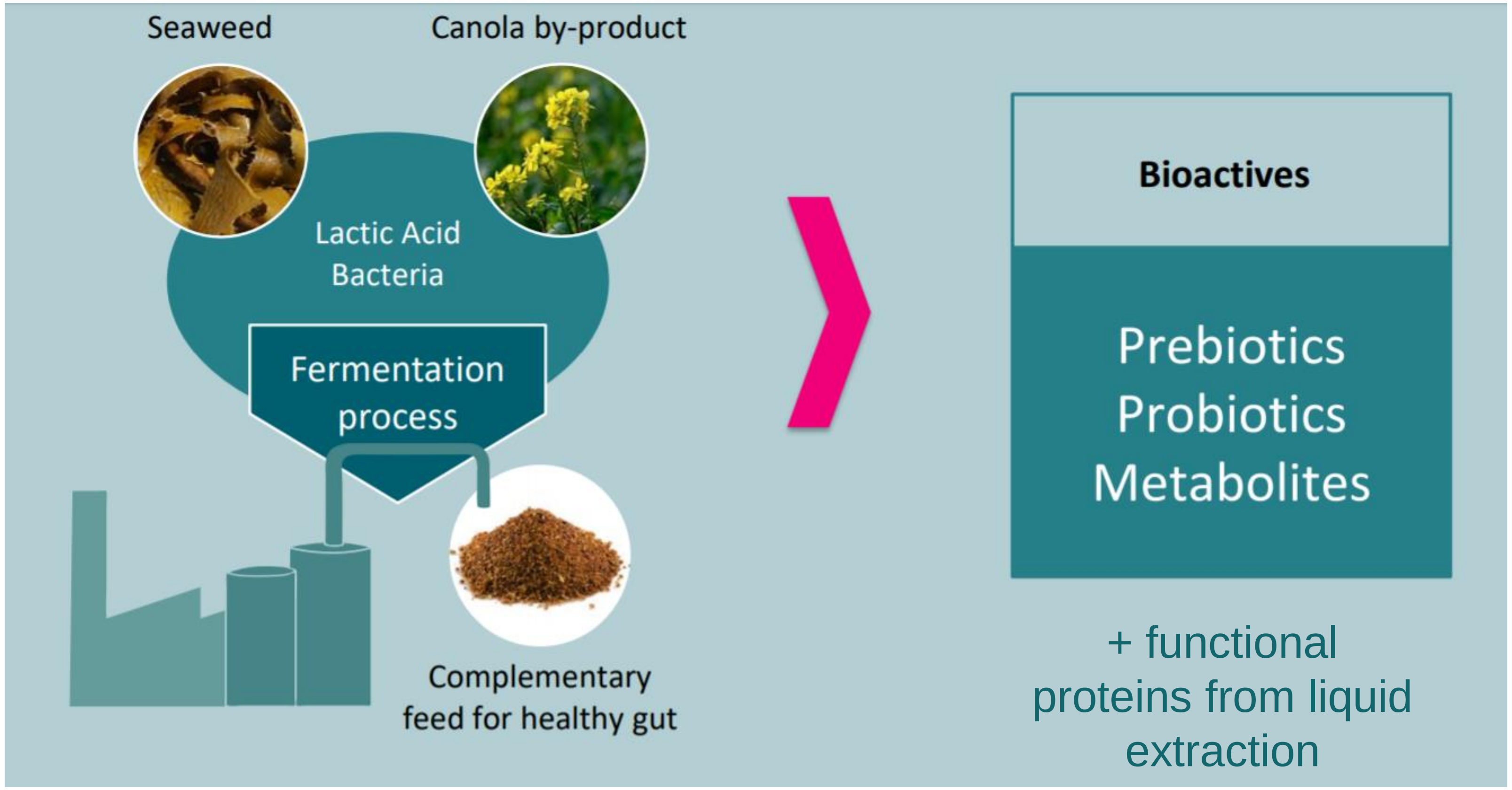
Social license

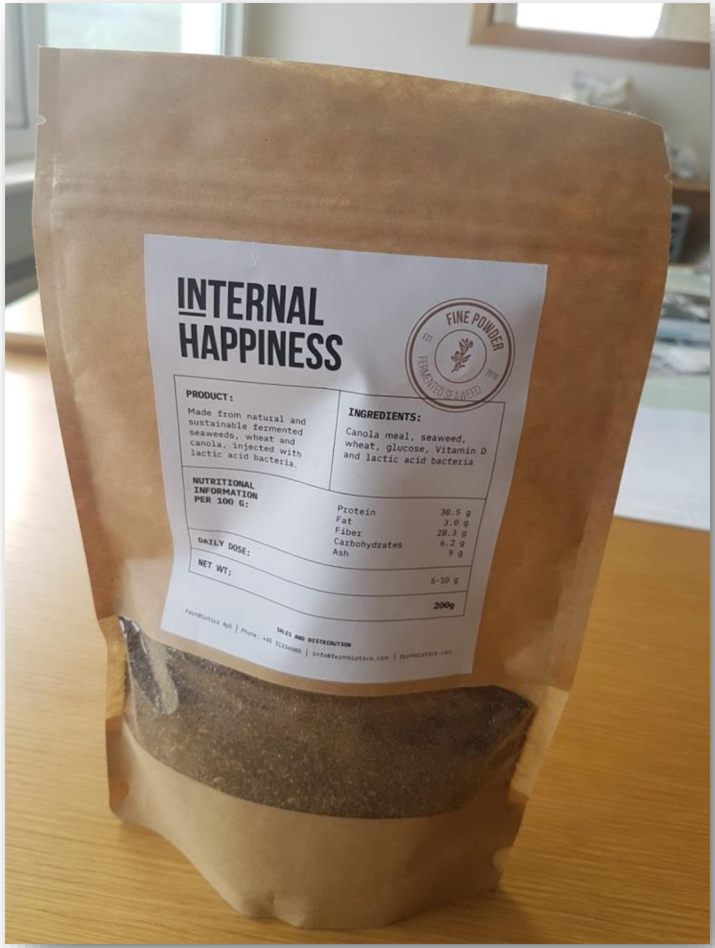
OCEAN RAINFOREST



Categories	Water depth	Distance to shore
Offshore	≥50 m	>3 NM
	<50 m	>3 NM
Nearshore exposed	≥50 m	<3 NM
Nearshore sheltered	<50 m	<3 NM

New feed & food product

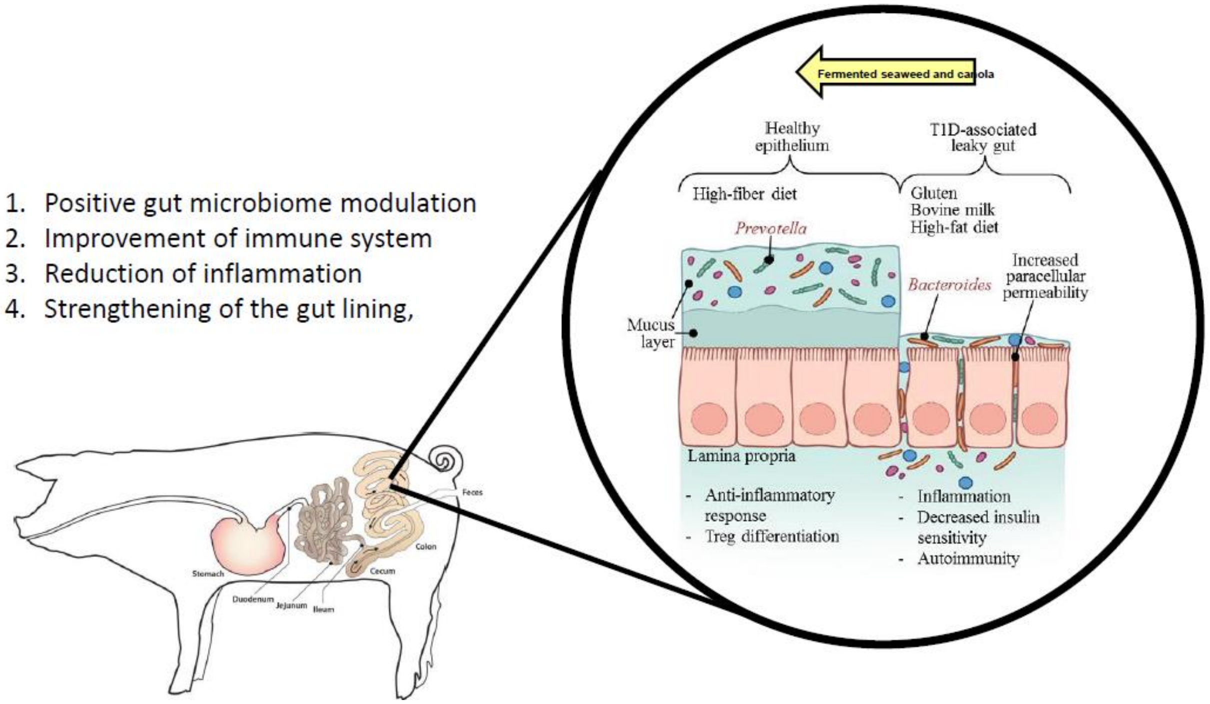




Functional ingredients for improved health in animals and human beings

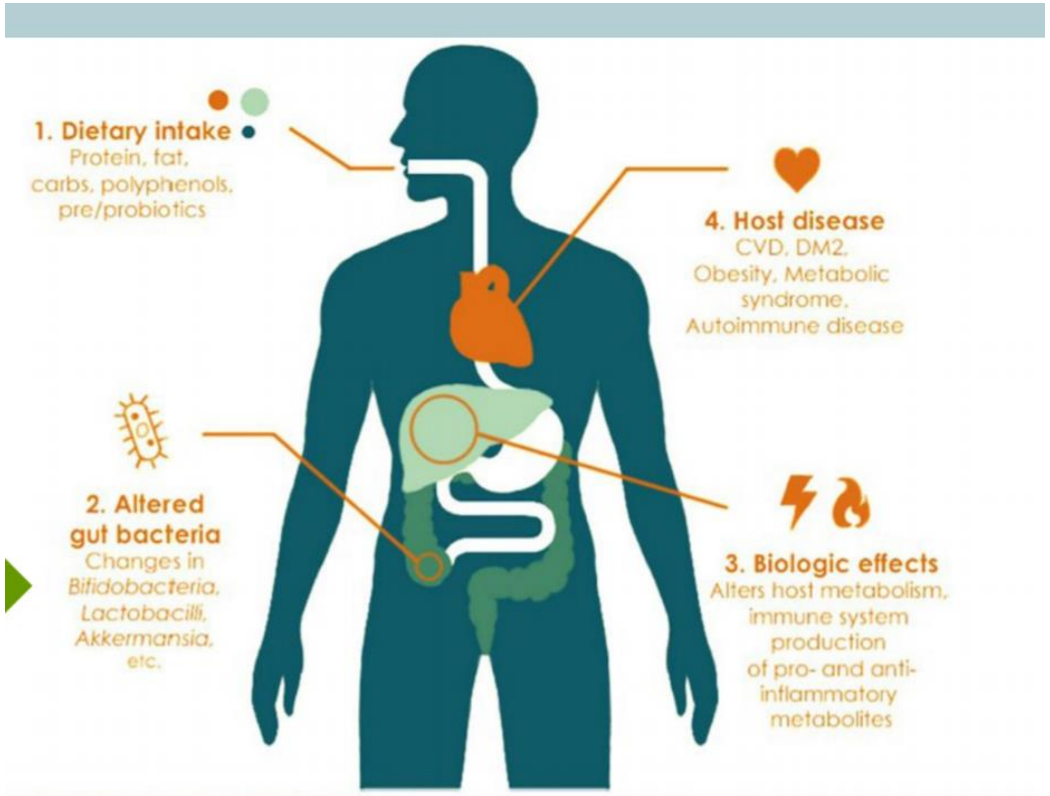
Tested on 600 pigs

1. Positive gut microbiome modulation
2. Improvement of immune system
3. Reduction of inflammation
4. Strengthening of the gut lining,



FERMENTATIONEXPERTS

Clinical Phase II trials on 30 patients with IBD:



Credit: *J Transl Med*. 2017; 15(1):73. doi: 10.1186/s12967-017-1175-y

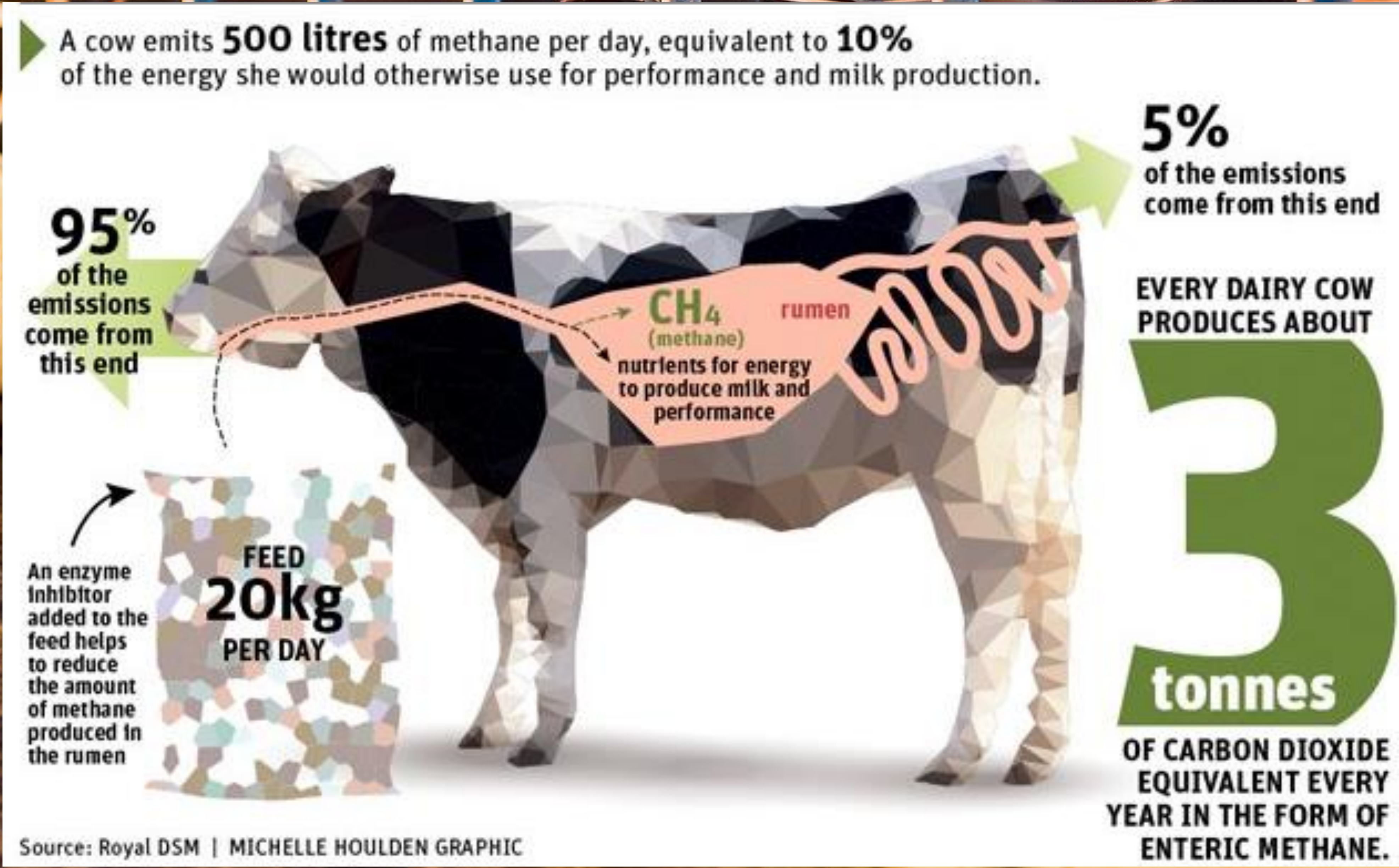
FermBiotics
Supporting gut health

Results from scientific test & farmers

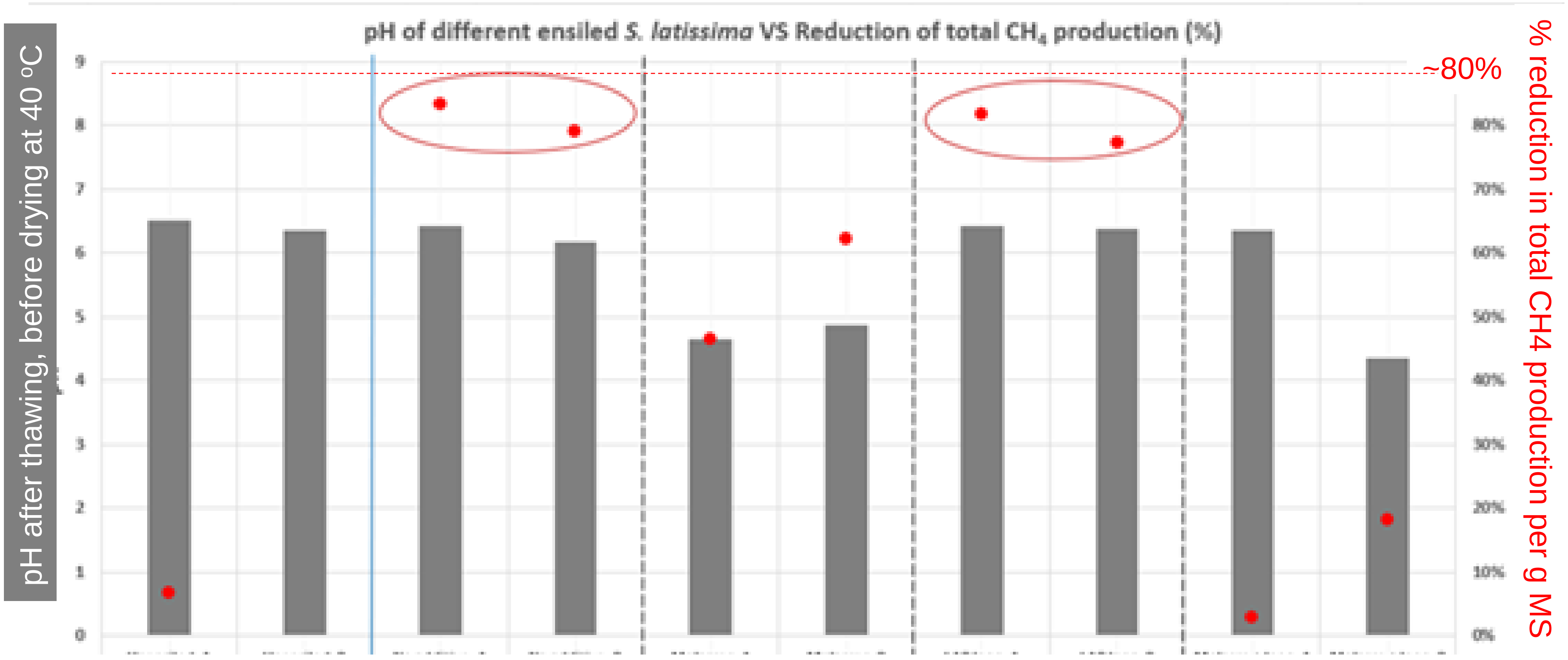
9% weight gain
7% reduced Feed Conversion Rate
3-4% reduced mortality
25-40% increase in antibodies

OCEAN RAINFOREST

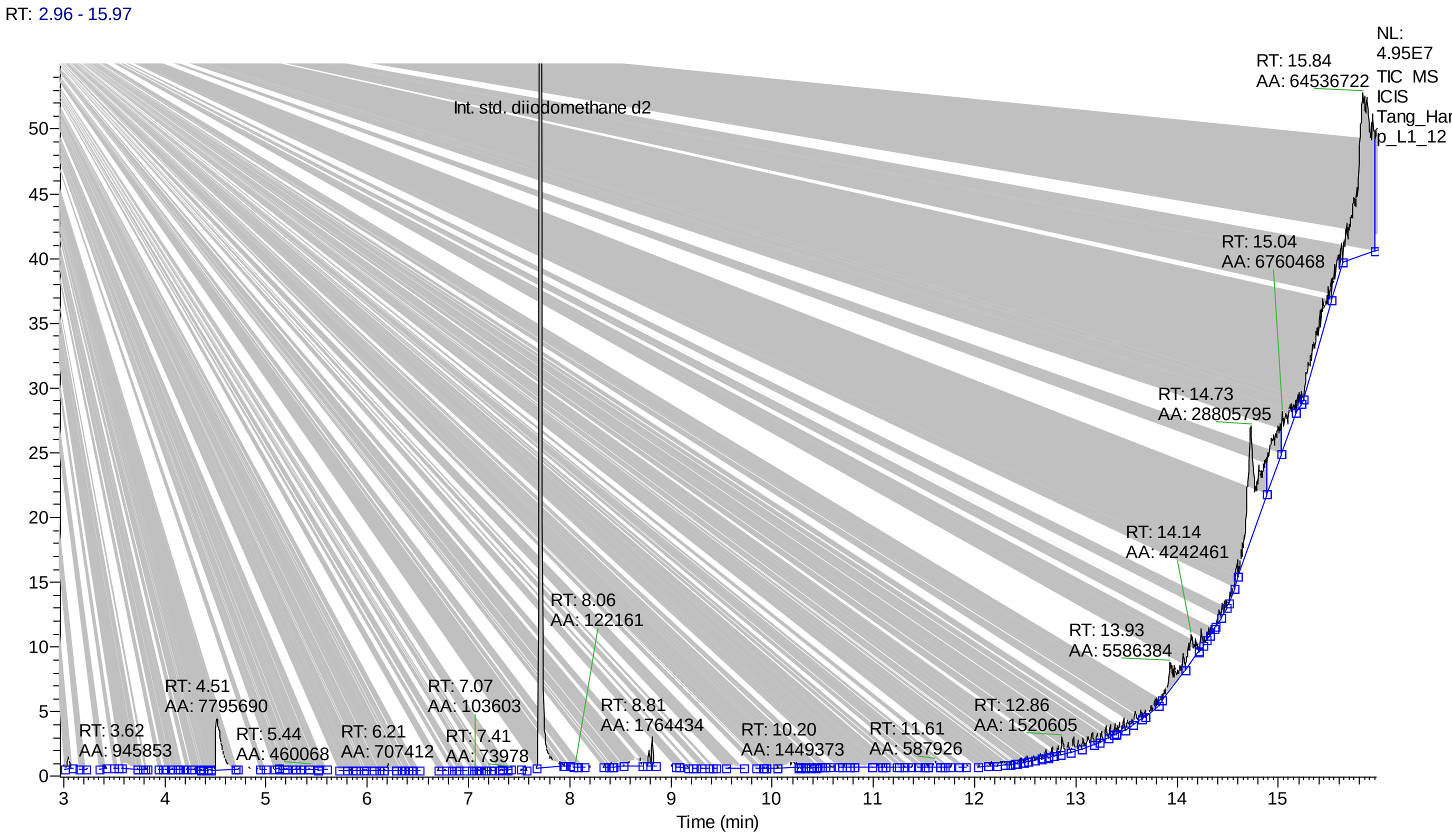
A climate neutral cow fed by sustainable seaweed



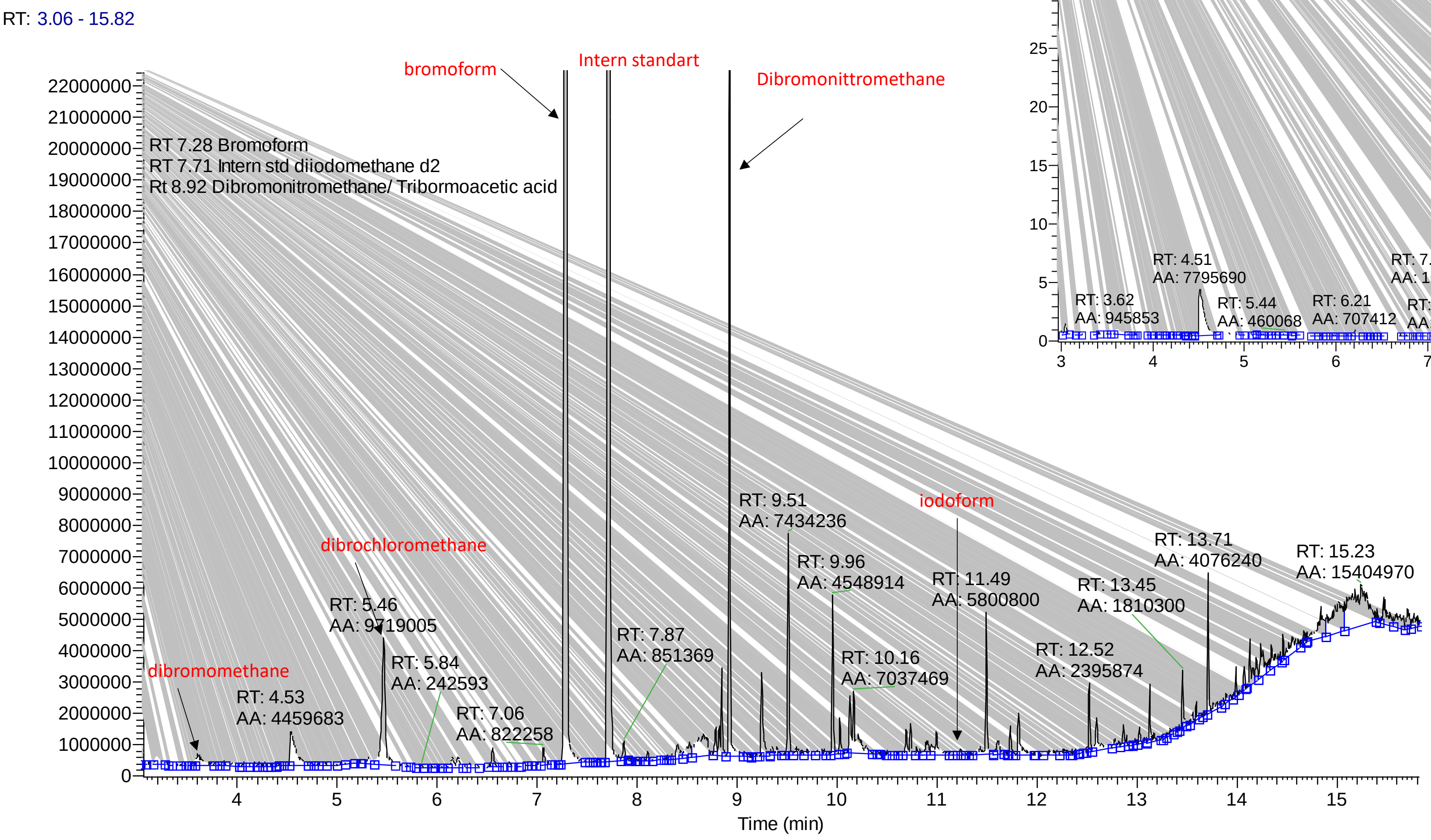
Results regarding ensiling: S latissima



Other seaweeds tested



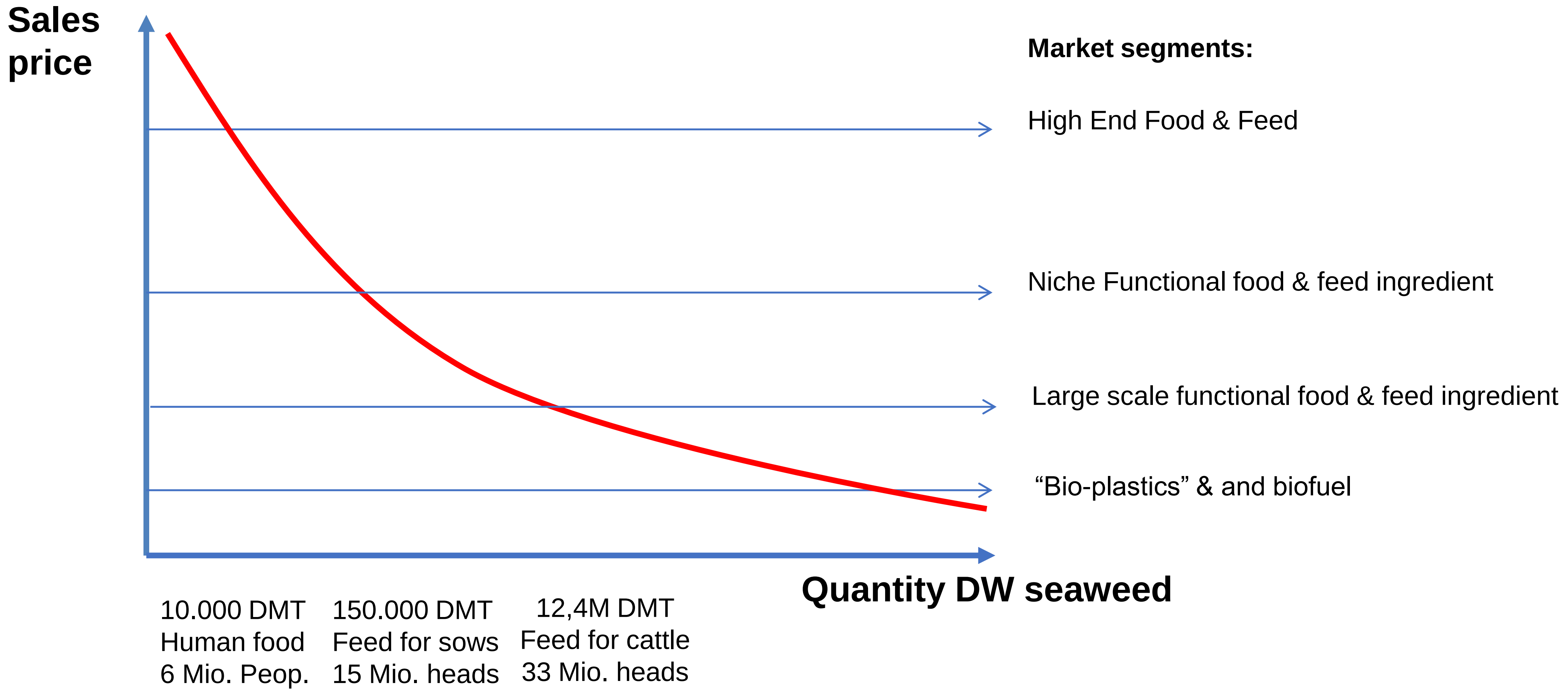
Asparagopsis Taxiformis



None of the Northern hemisphere macroalgae have detectable levels of halogenated carbons

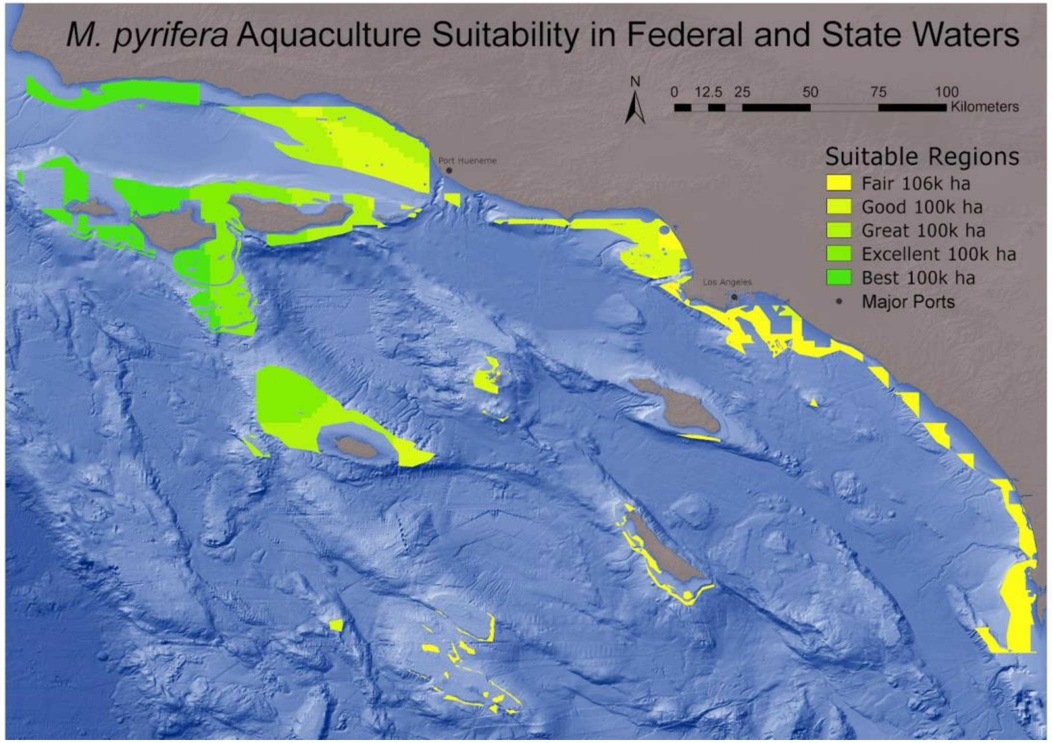
Climate Feed

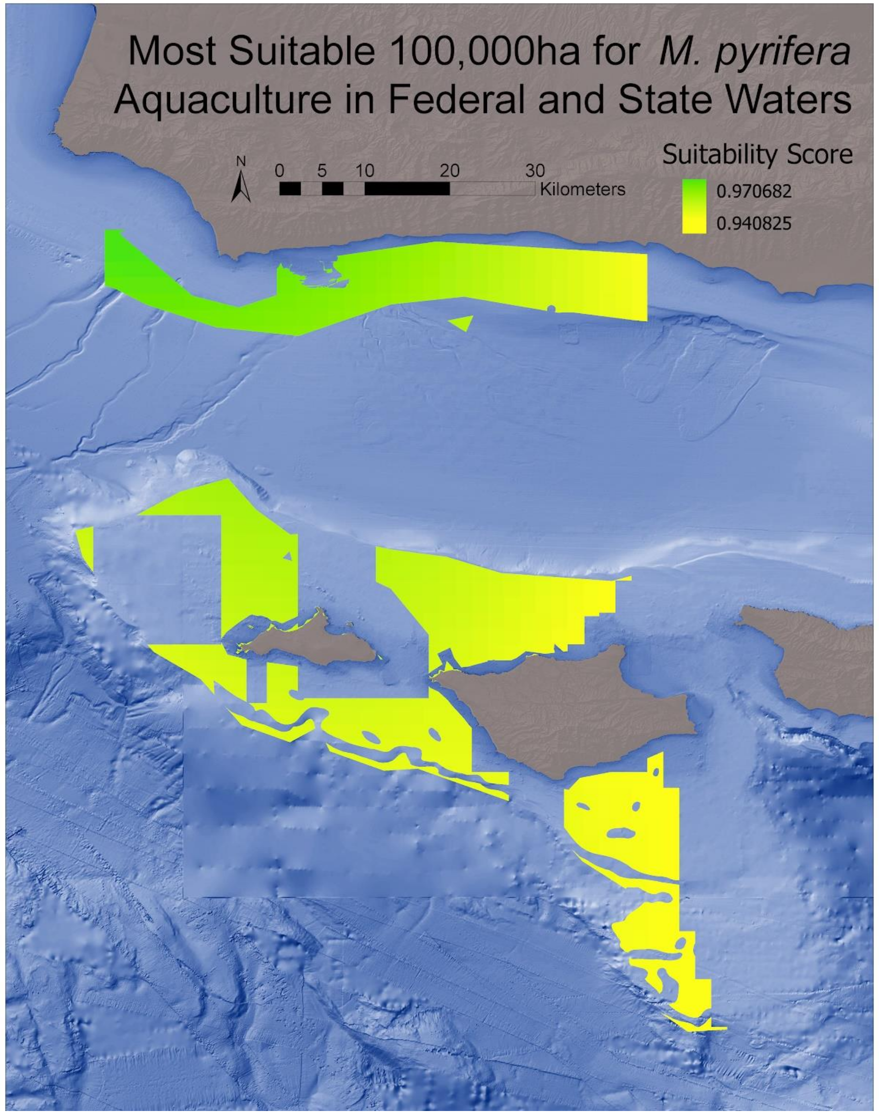
The challenge of upscaling vs. market segments



>500,000 ha of Suitable Cultivation Area in Federal and State Waters on the California Continental Shelf <200m depth

Suitability maps have been created for Federal and state waters utilizing a normalized weighted suitability scale. Each category listed is considered suitable to varying degrees. Each environmental parameter in the weighted suitability model is equal. Offshore southern California, 508,660 total hectares in Federal and state waters have been identified with 386,101 hectares in Federal waters, well above the initial proposal goal of 100,000 hectares.





MACRO SYSTEMS

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OCEAN RAINFOREST SUSTAINABLE NORDIC SEAWEED
PATAGONIA SEAWEEDS
Hortimare
PRIMARY OCEAN PRODUCERS

Need for Research & Development

- Logistics in relation to large scale deployment, seeding and harvest offshore
- Verify prediction models on growth & harvest
    - Usage of remote sensory technology
- Large scale processing on- or offshore
- Product and market development with convincing data on value propositions/claims

OCEAN RAINFOREST

OCEAN
RAINFOREST

A local ocean rainforest around the world

Oceanrainforest.com

Ocean Rainforest

@Orainforest

CLIMATE FOUNDATION

Marine Permaculture

National Academy of Science,
Engineering and Medicine
February 2nd 2021

Brian von Herzen,
Ph.D., Executive Director
brian@climatefoundation.org
+1 (650) 942-9630

Our Mission

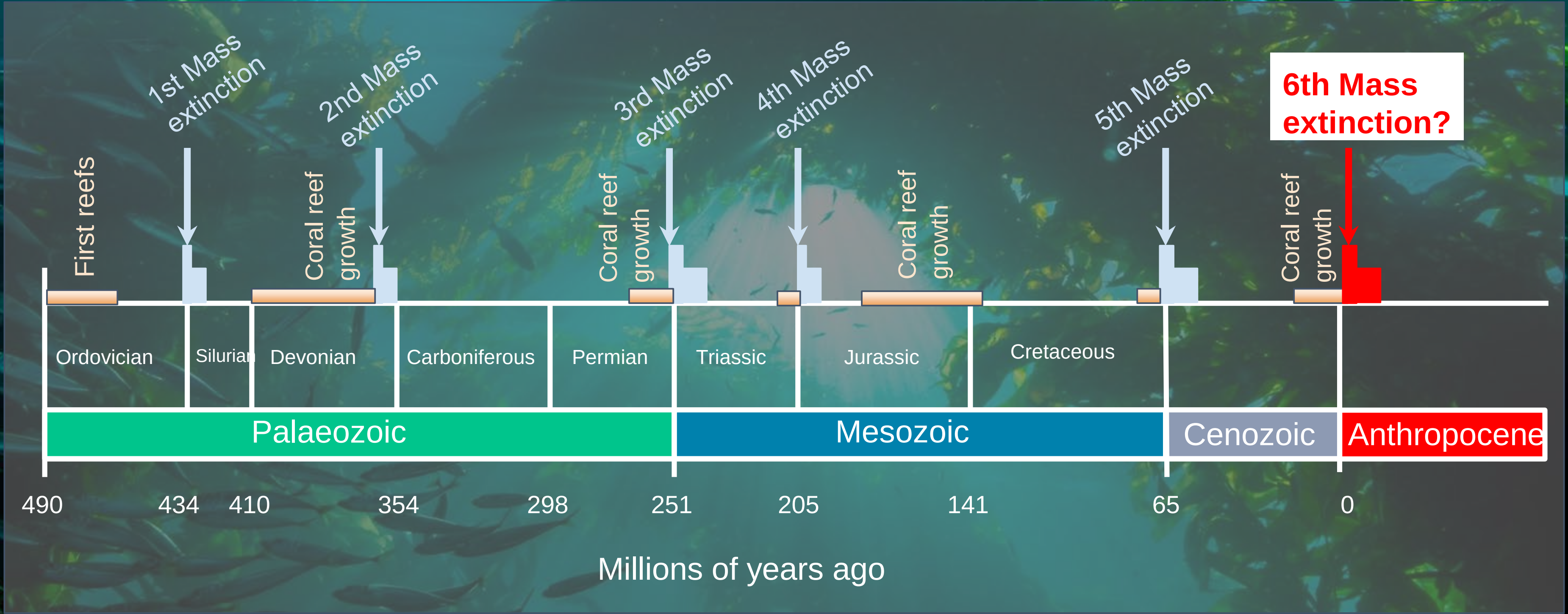
Restore life in the oceans to create a thriving & sustainable ocean economy

Sustainable Ocean Livelihoods

Ecosystem Regeneration

Carbon Balance

Earth's **five mass extinction** events and coral reef growth

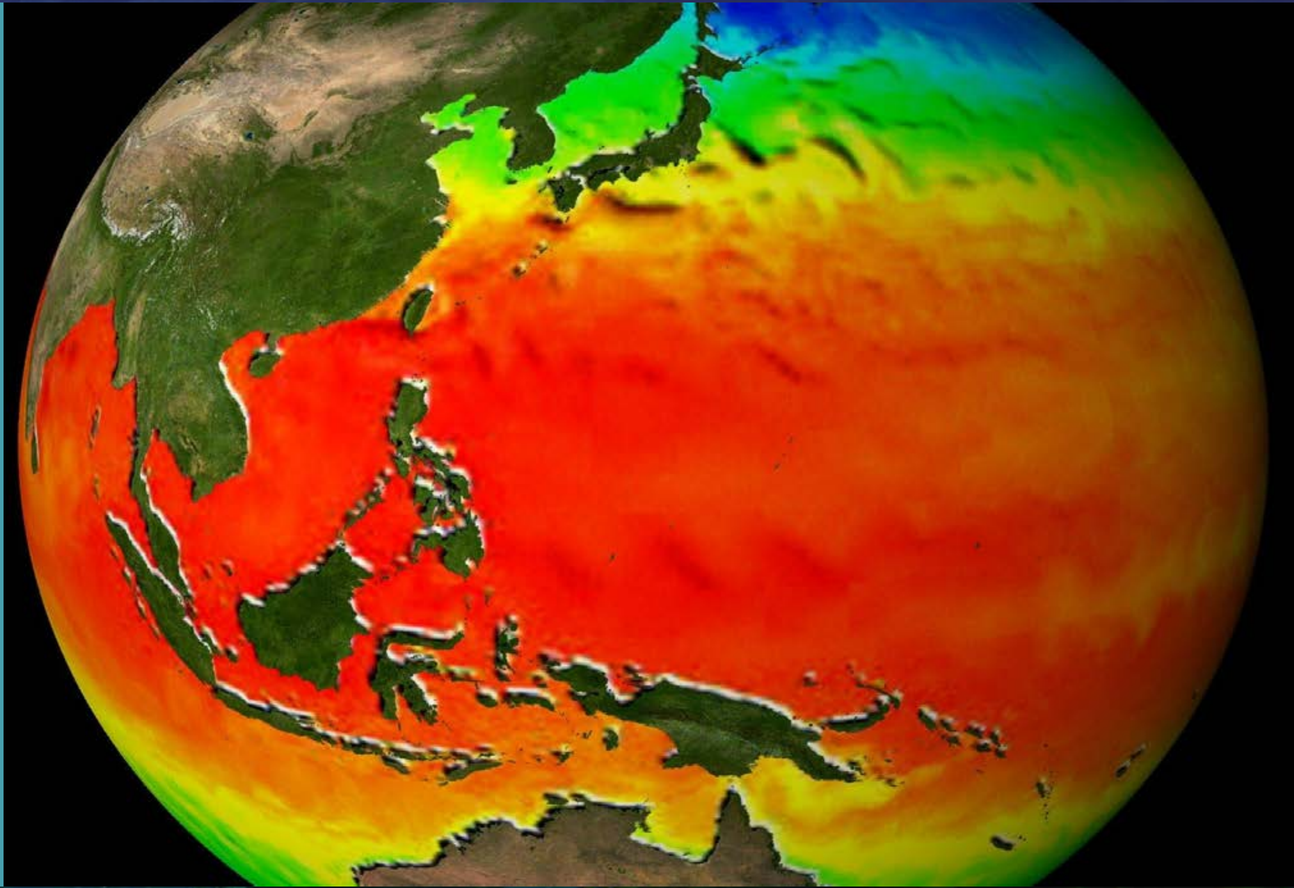


Veron, 2008

The Global Problem

93%

of the heat captured by **greenhouse gases** ends up in the **upper ocean**

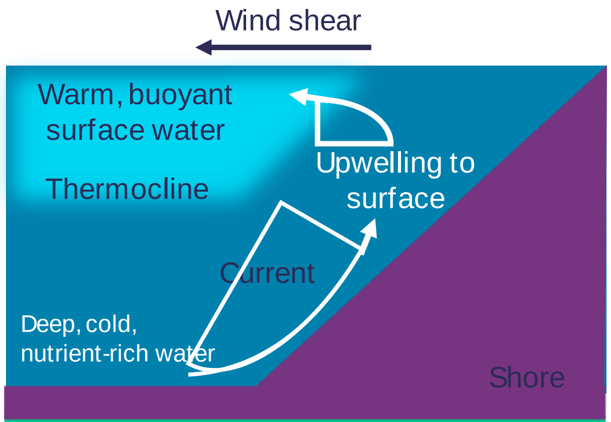


End-Permian warming slowed overturning circulation through the thermocline

- **“The Permian–Triassic boundary** (PTB, ~252.3 Ma) **marks the largest mass extinction** of the Phanerozoic, with a loss of more than 90% of marine organisms.” [emphasis added]
- “The PTB global warming ... likely led to severe environmental consequences, such as ocean acidification, a decline in the marine productivity, and extensive hypoxia.”
- “The response of the PTB ocean circulation to an atmospheric perturbation of ~5000 Pg C ... leads to a global temperature increase by 3–4 °C and **an increase in ocean stratification**.”
- **“The scenario with reduced cloud albedo further leads to an increase in ocean stratification and widespread low-oxygen concentrations** in the Panthalassa during the Early Triassic.”

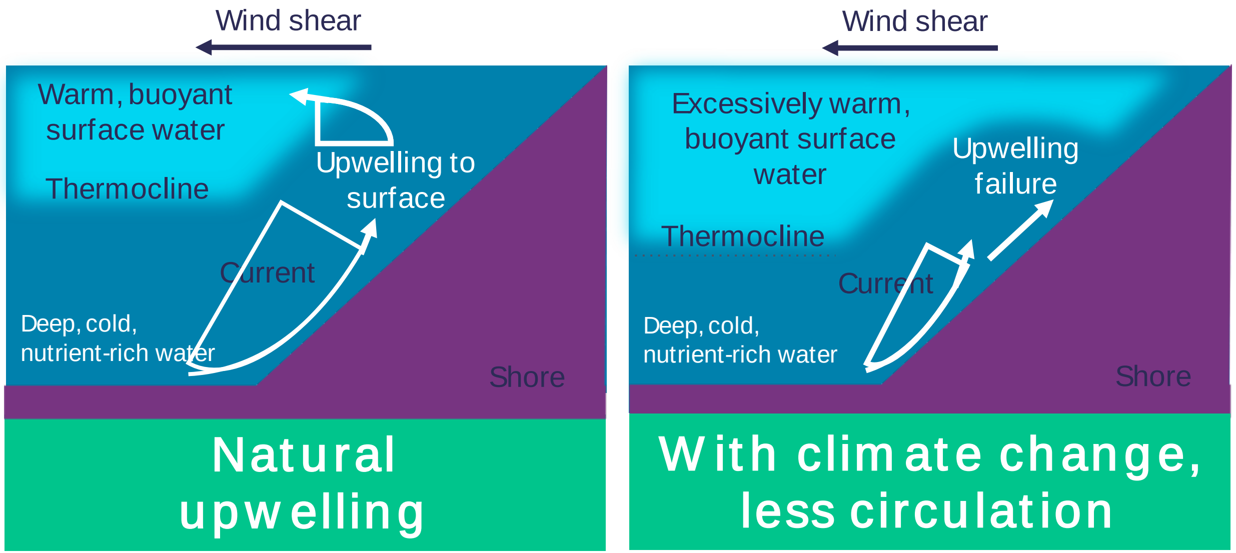
From Winguth et al. (2015).

Sustainable nutrient cycles in the sea

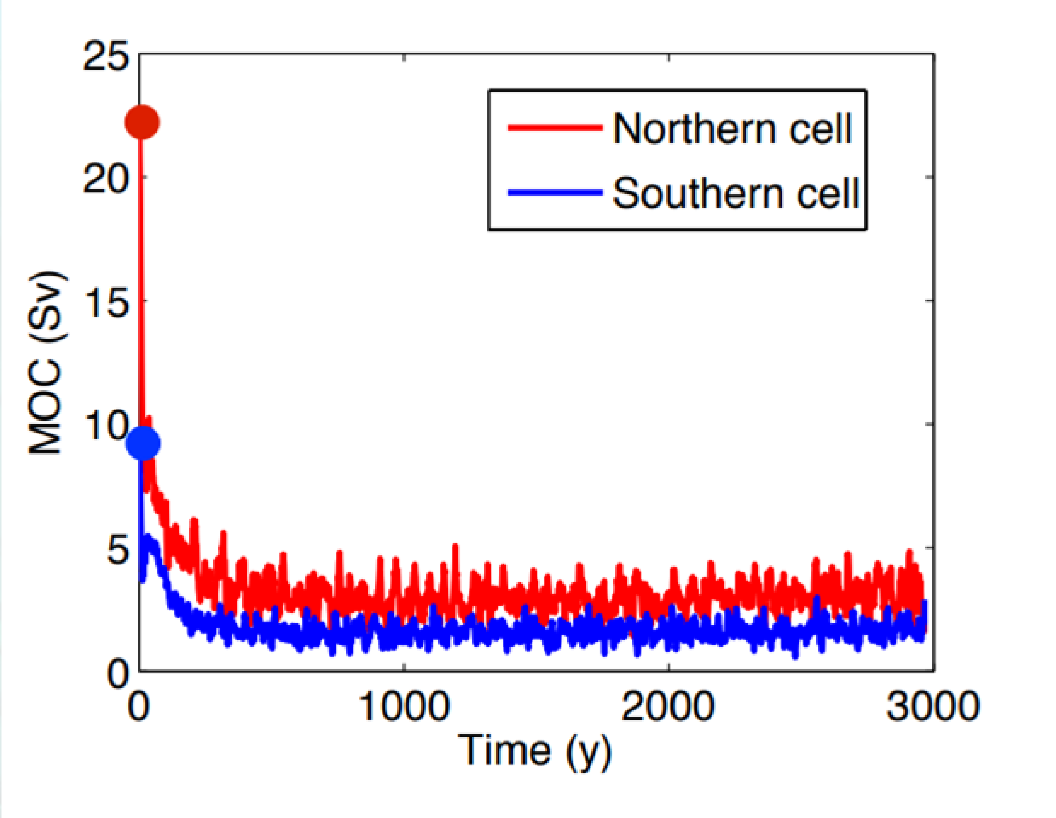


Natural upwelling

Sustainable nutrient cycles in the sea

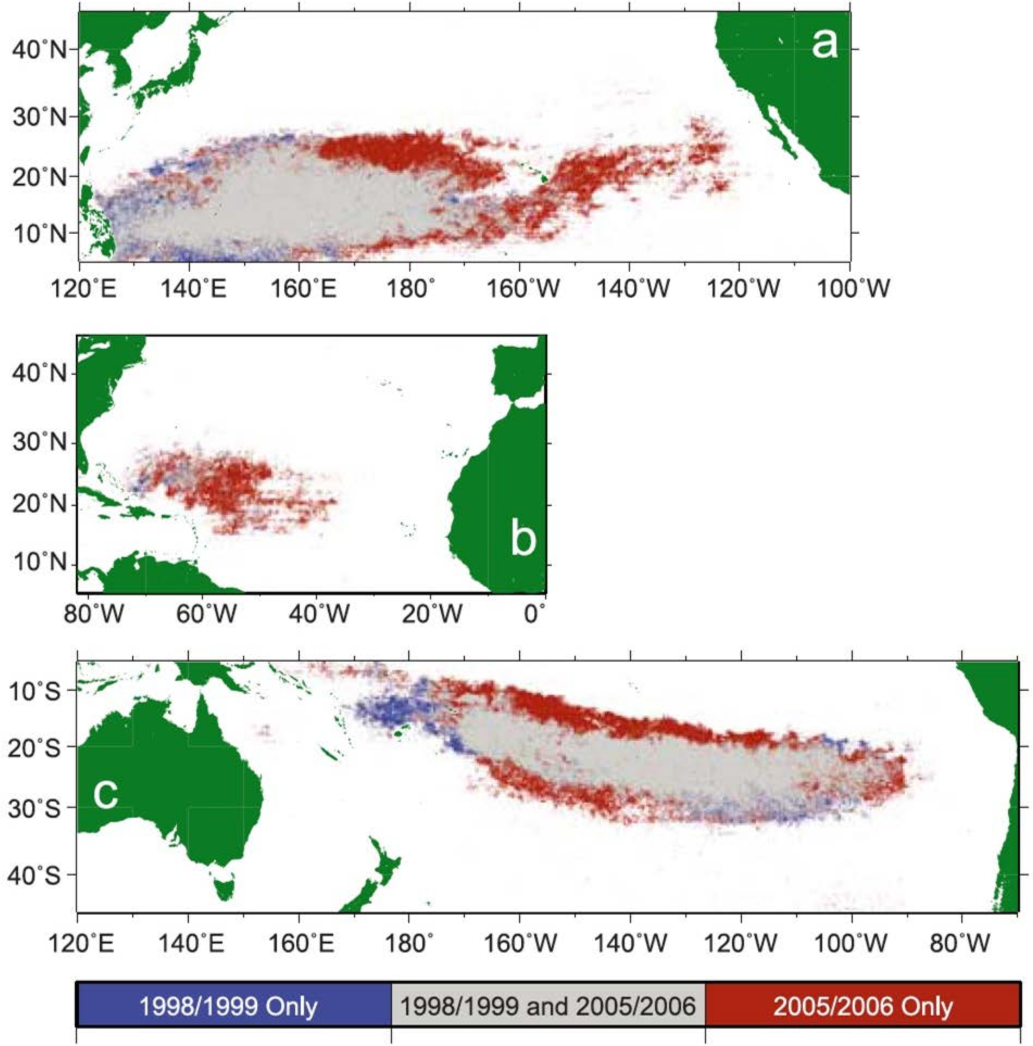


Modeled decrease in Meridional Overturning Circulation (MOC) at PTB



J.L. Penn, C. Deutsch, J.L. Payne, E.A. Sperling. (2018). Temperature-dependent hypoxia explains biogeography and severity of end-Permian marine mass extinction. *Science* vol. 362, 6419.

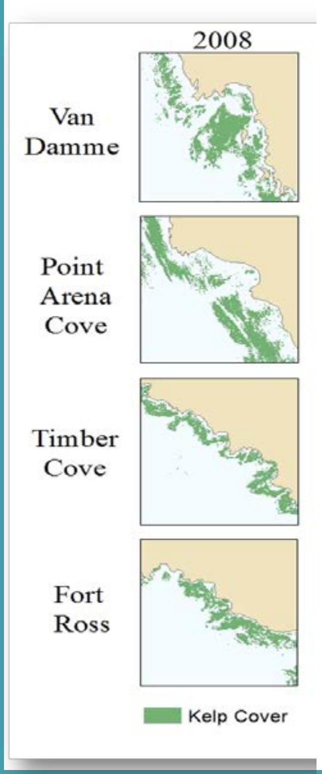
Oligotrophic Oceanic Regions are Growing



Jeffrey J. Polovina, Evan A. Howell, and Melanie Abecassis
Ocean's least productive waters are expanding
GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L03618,
doi:10.1029/2007GL031745, 2008

The Upwelling Failure

Dramatically decimated kelp cover between 2008 and 2014, in California.



https://cdfwmarine.file.wordpress.com/2016/03/kelpcovermap2008-2014.png

The Upwelling Failure

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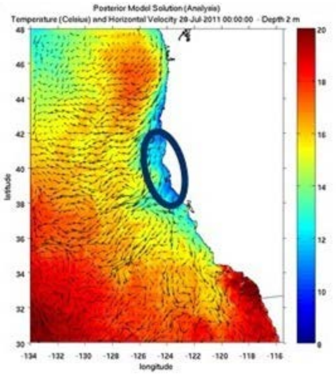
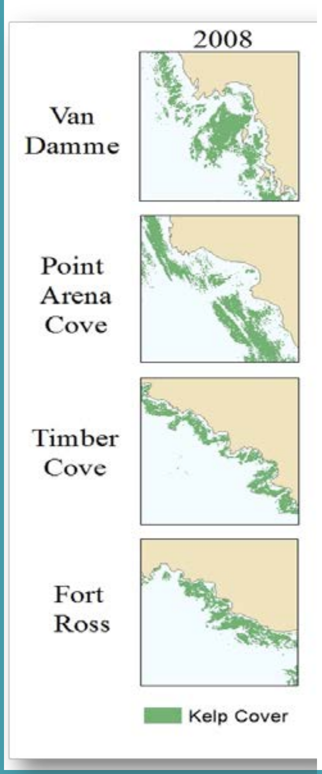


July 28, 2011
Normal Conditions

https://cdfwmarine.files.wordpress.com/2016/03/watertemps1.jpg



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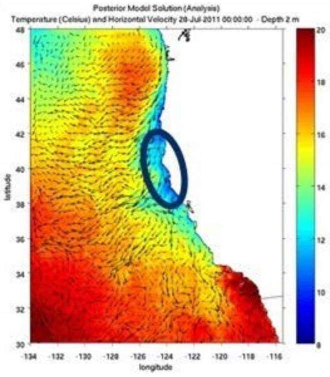
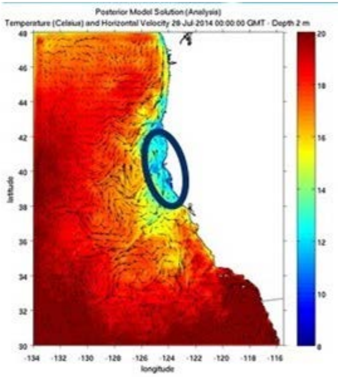
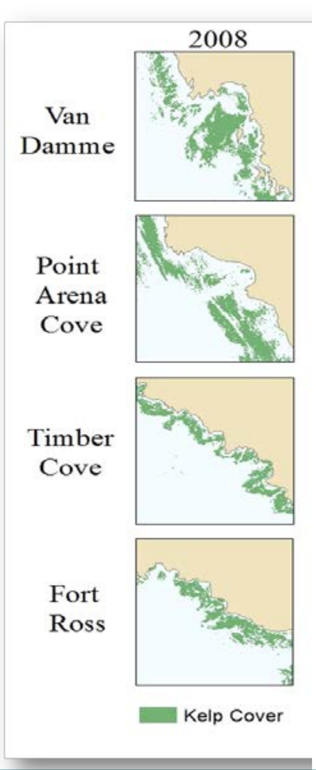


July 28, 2011
Normal Conditions



July 28, 2014
“Warm Blob”

https://cdfwmarine.files.wordpress.com/2016/03/watertemps1.jpg



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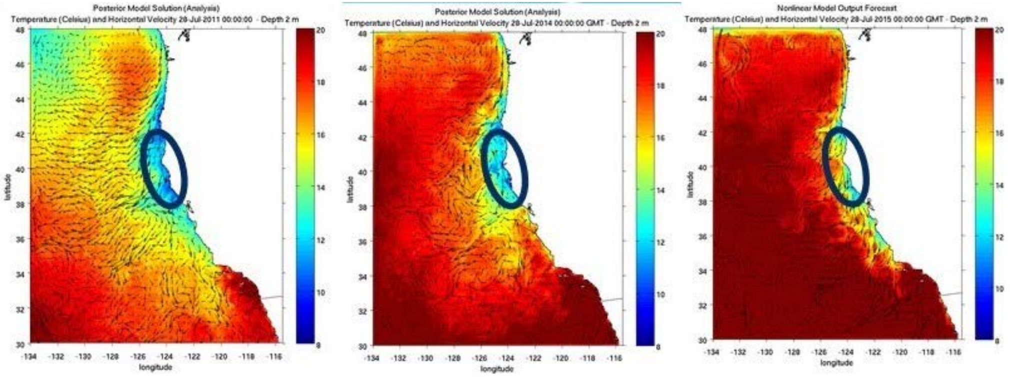
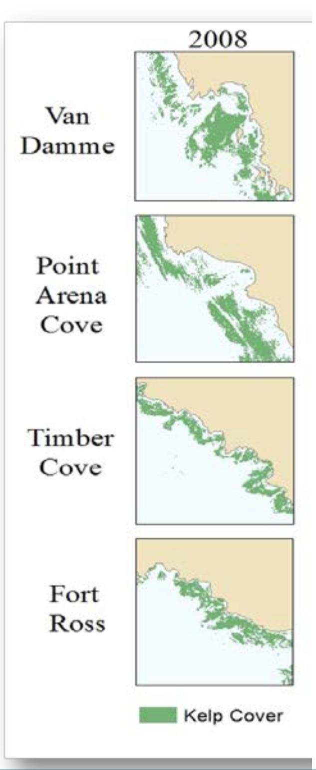


July 28, 2011 Normal Conditions	July 28, 2014 “Warm Blob”	July 28, 2015 “Warm Blob” + Strong El Niño

https://cdfwmarine.files.wordpress.com/2016/03/watertemps1.jpg



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The Upwelling Failure

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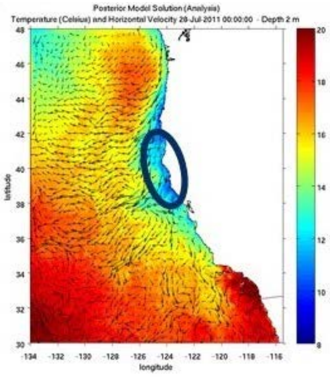
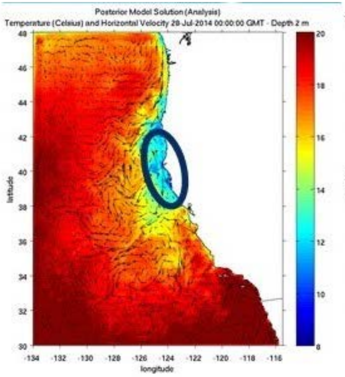
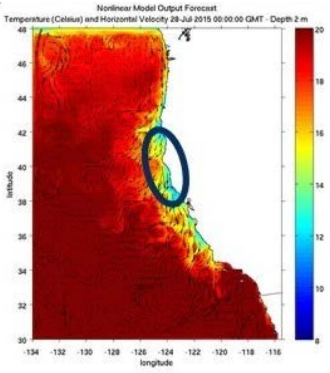


July 28, 2011
Normal Conditions

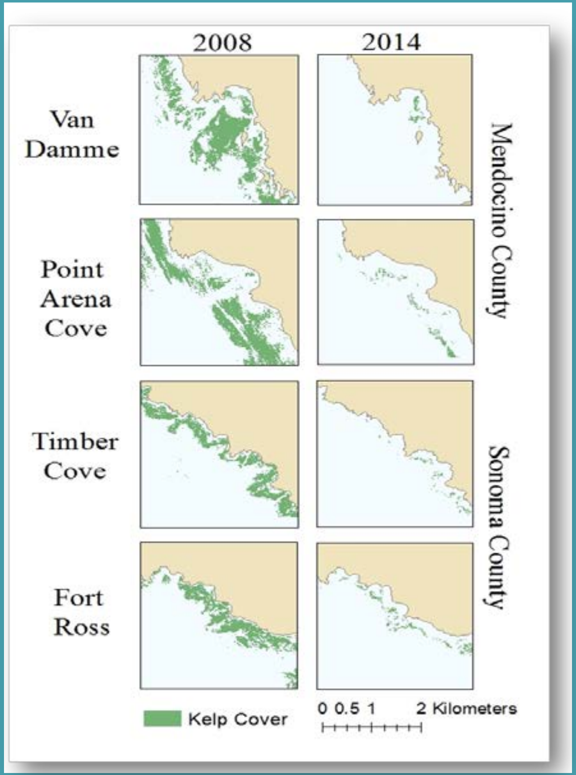


July 28, 2014
"Warm Blob"



July 28, 2015
"Warm Blob" +
Strong El Niño

https://cdfwmarine.files.wordpress.com/2016/03/watertemps1.jpg



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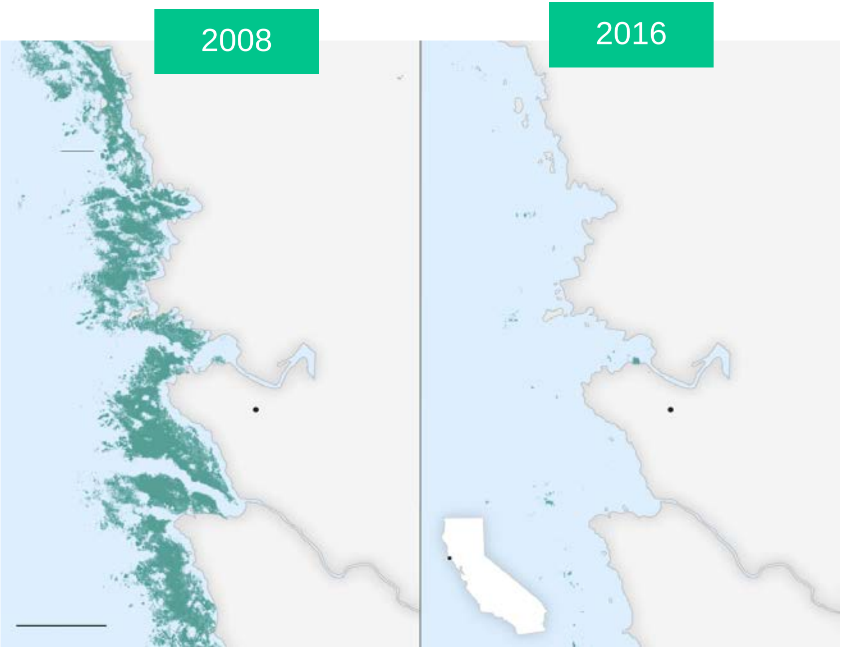


Source: California Department of Fish and Wildlife

93% decline
due to:

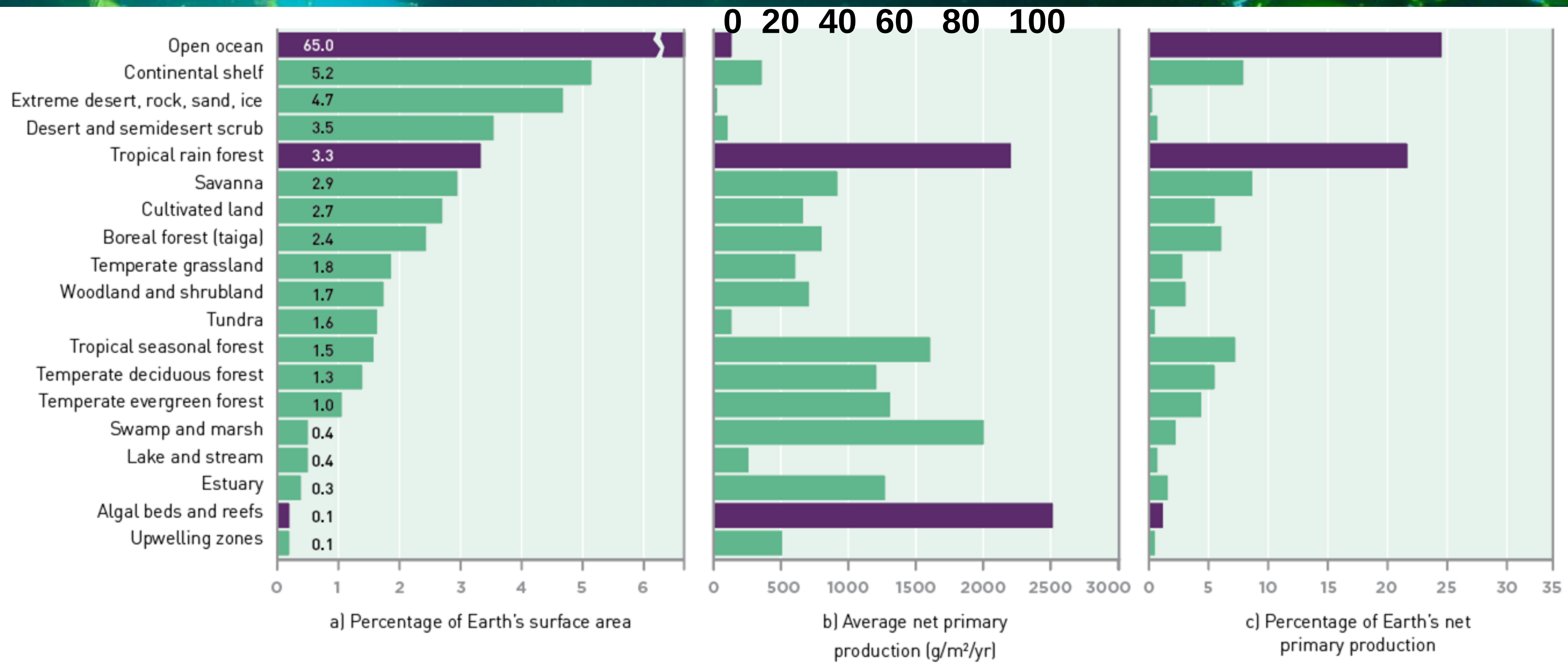
- Slowed process of upwelling
- Higher temperatures
- Less nutrients
- Absence of sea urchin predators
- Purple urchins grazing the seafloor

The potential of open ocean for macro algae kelp production

Carbon fixation CO2e (tonnes/hectare/yr)

Chart 01

Primary Productivity of ecosystems showing seaweed (algae) beds as the most productive per unit area.



The potential of open ocean for macro algae kelp production

Chart 01

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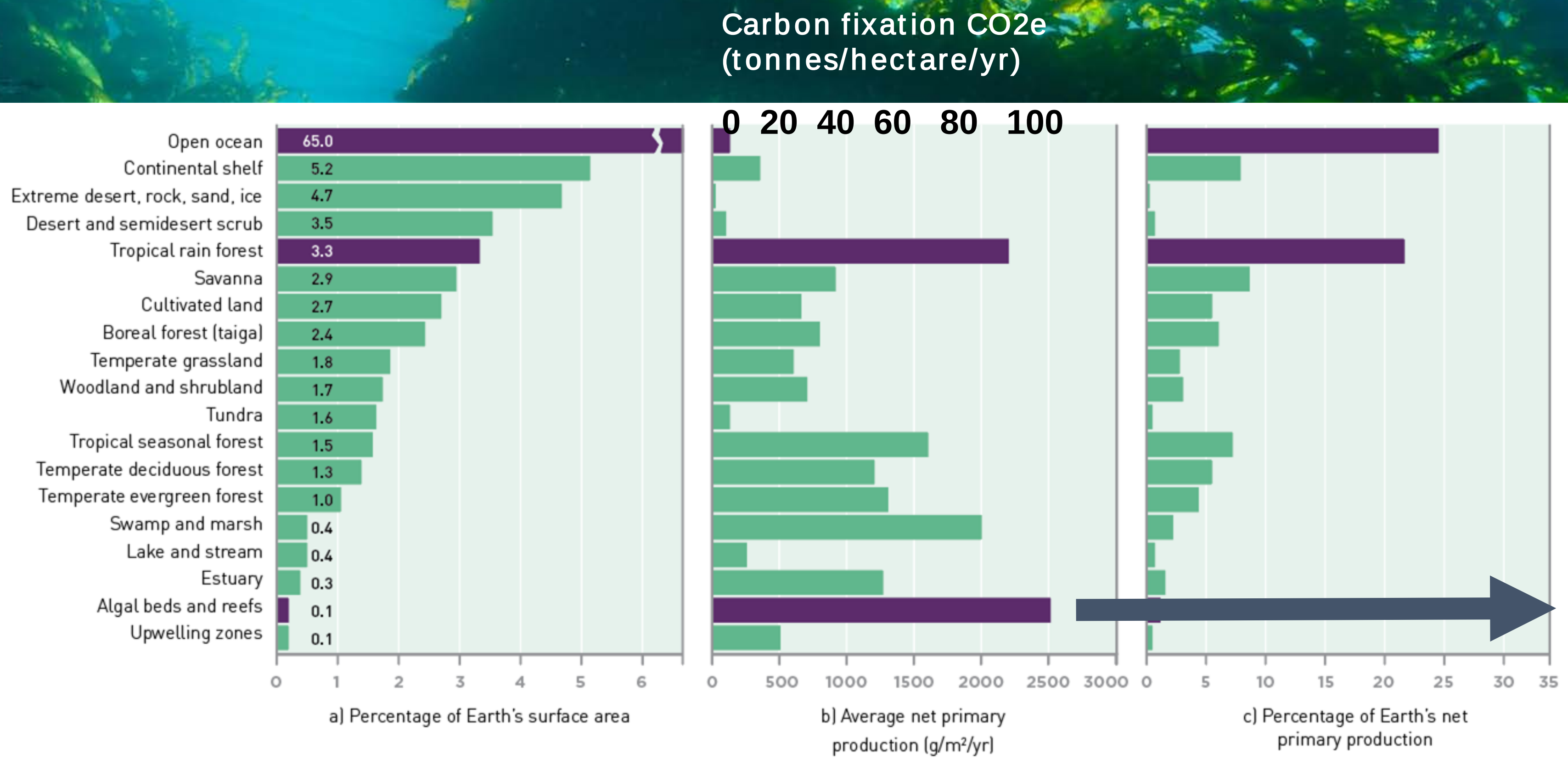
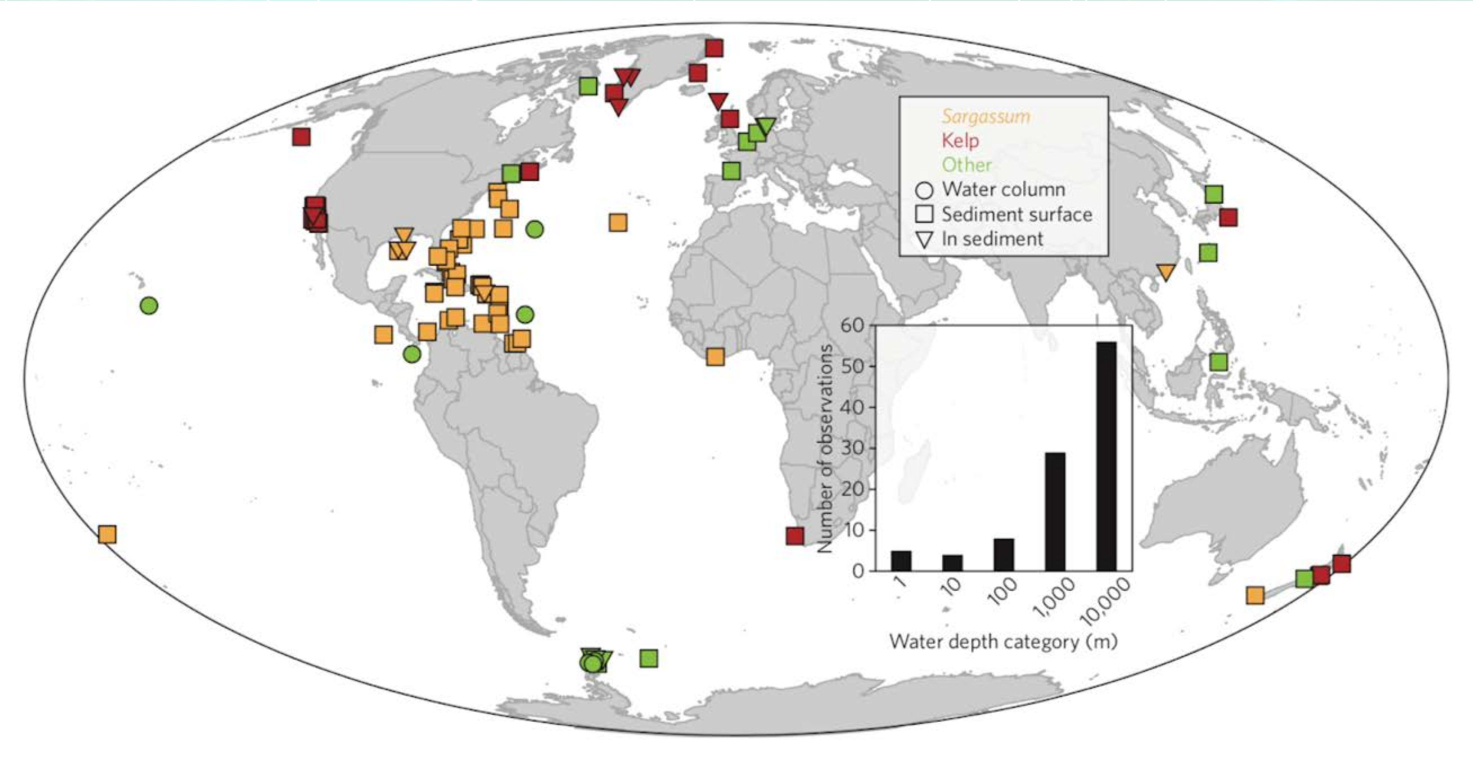


Role of macroalgae in carbon sequestration

0.4 gC m–2 yr–1 of *Sargassum is* reaching 3,600 m depth in the Northwest Atlantic

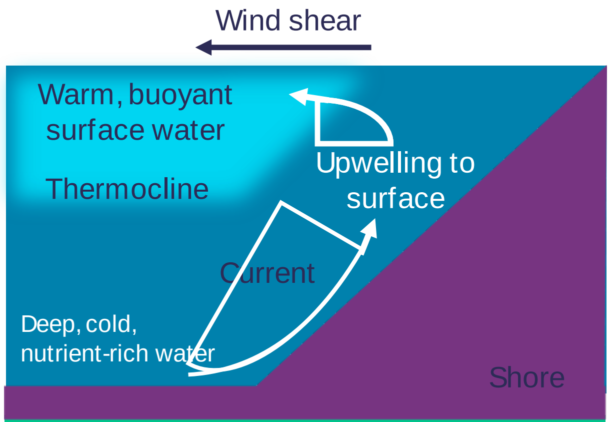
(Rowe, G., & Staresinic, N. (1979). Sources of Organic Matter to the Deep-Sea Benthos. Ambio Special Report, (6), 19-23.)



Dorte Krause-Jensen, & Carlos M. Duarte. (2016). Substantial role of macroalgae in marine carbon sequestration. Nature Geoscience, 9(10), 737-742.

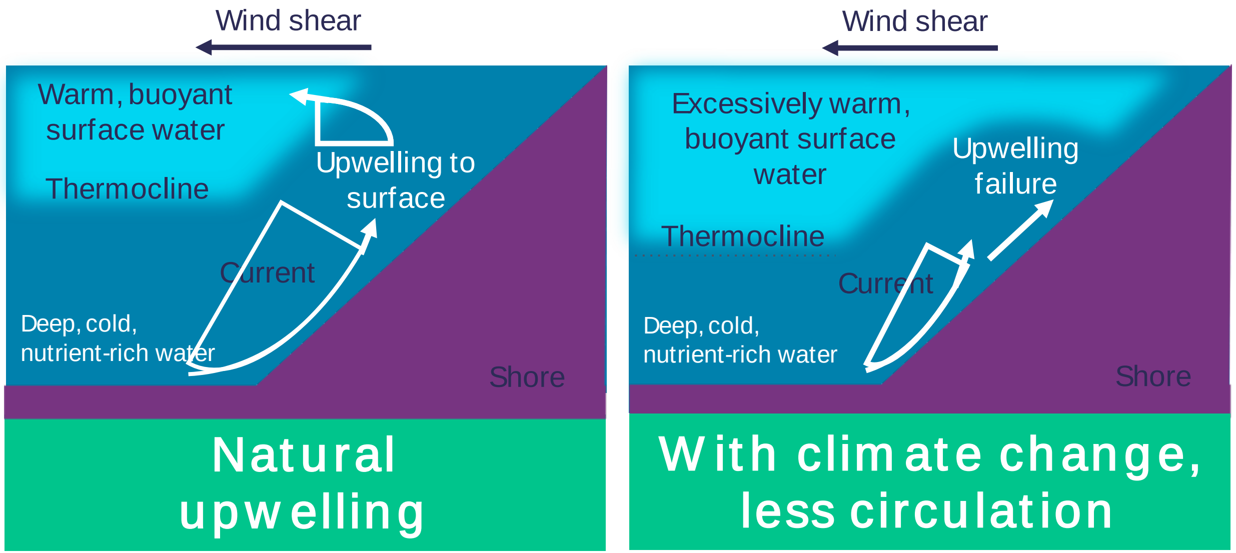
Solution

Sustainable nutrient cycles in the sea

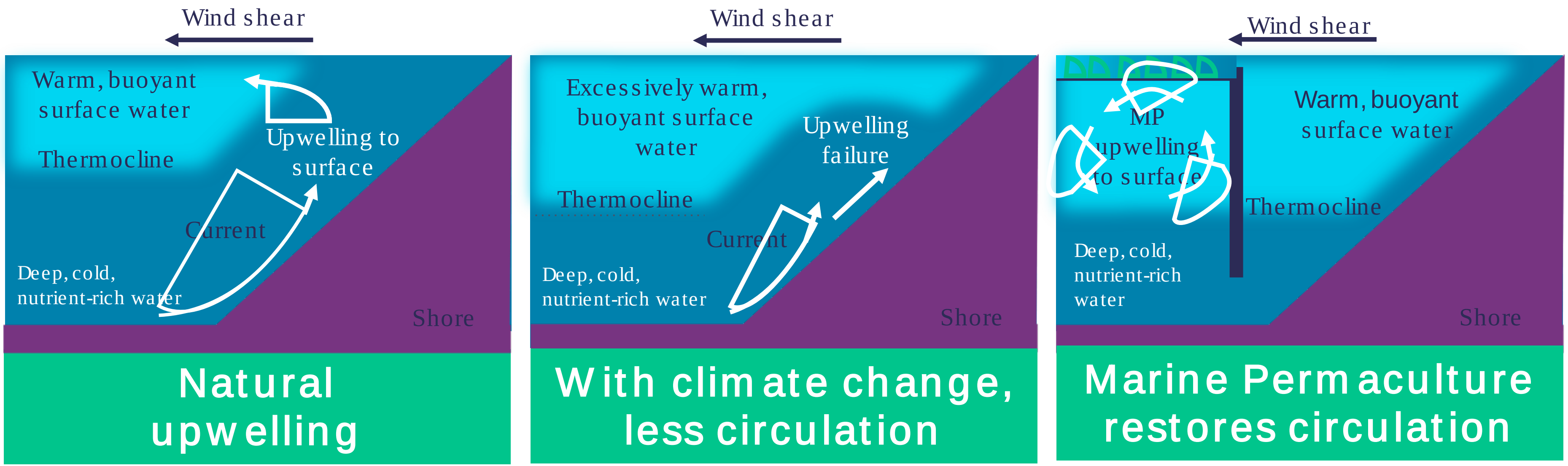


Natural upwelling

Sustainable nutrient cycles in the sea



Sustainable nutrient cycles in the sea



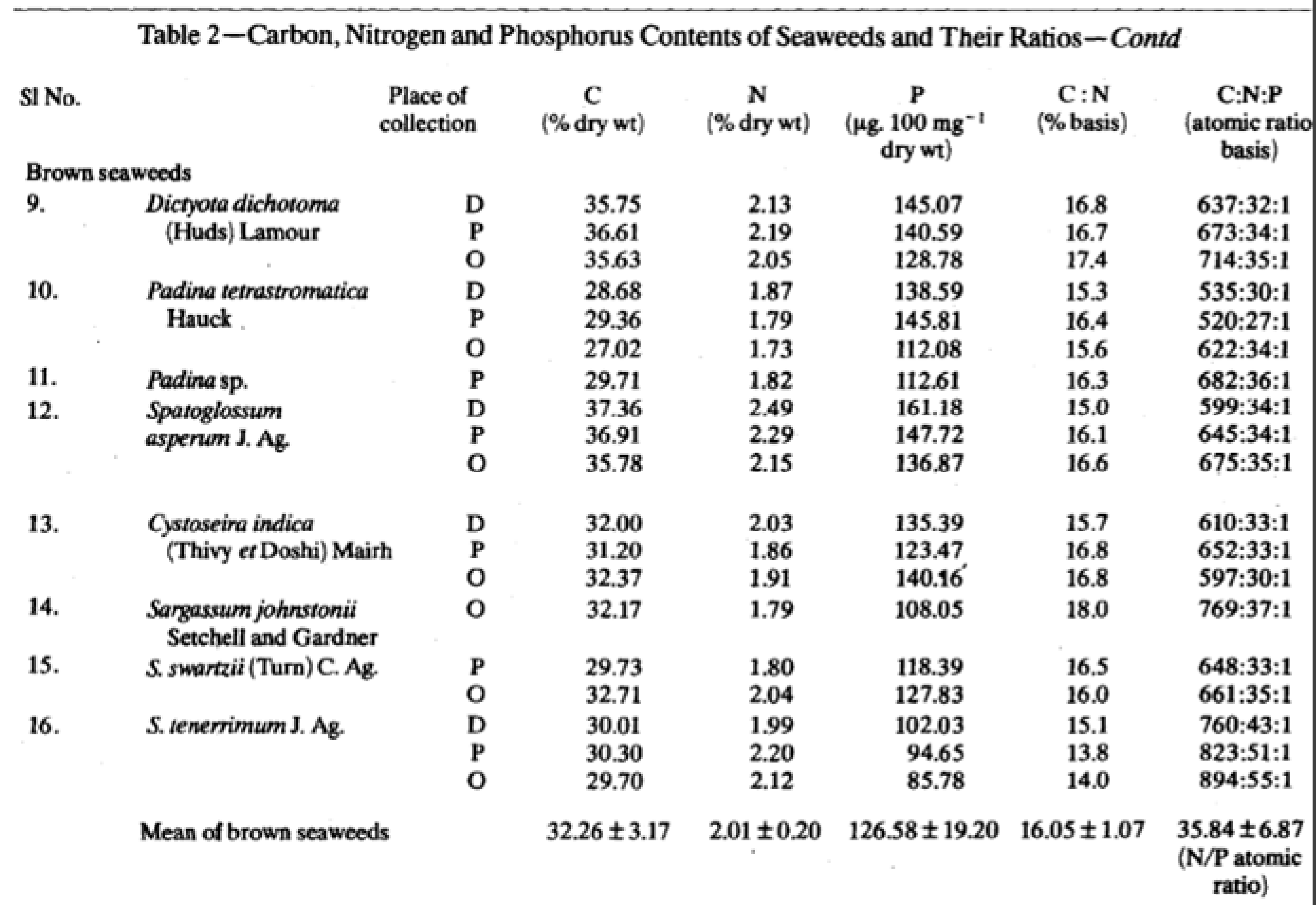


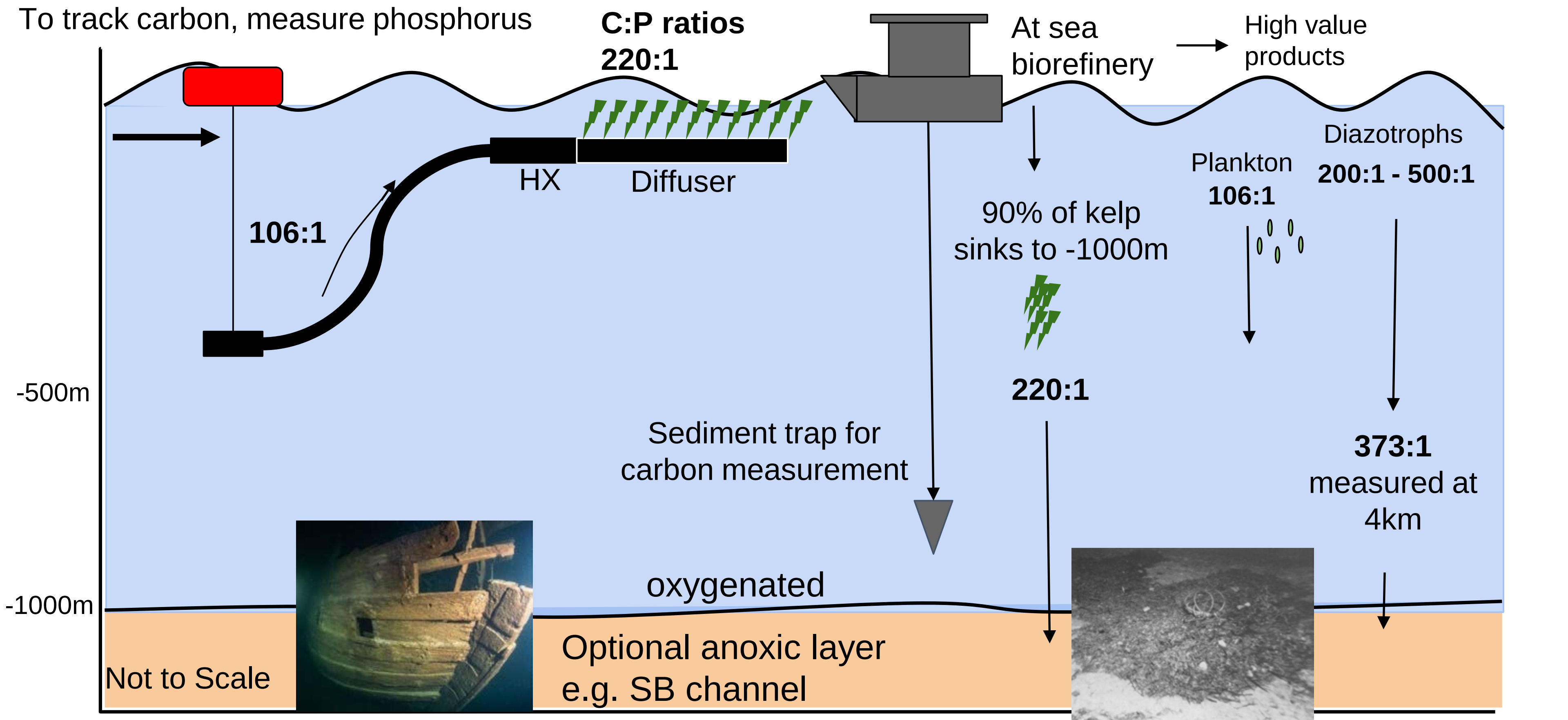
Table 2—Carbon, Nitrogen and Phosphorus Contents of Seaweeds and Their Ratios—*Contd*

Sl No.		Place of collection	C (% dry wt)	N (% dry wt)	P (μg. 100 mg⁻¹ dry wt)	C : N (% basis)	C:N:P (atomic ratio basis)
Brown seaweeds							
9.	*Dictyota dichotoma* (Huds) Lamour	D	35.75	2.13	145.07	16.8	637:32:1
		P	36.61	2.19	140.59	16.7	673:34:1
		O	35.63	2.05	128.78	17.4	714:35:1
10.	*Padina tetrastromatica* Hauck	D	28.68	1.87	138.59	15.3	535:30:1
		P	29.36	1.79	145.81	16.4	520:27:1
		O	27.02	1.73	112.08	15.6	622:34:1
11.	*Padina* sp.	P	29.71	1.82	112.61	16.3	682:36:1
12.	*Spatoglossum asperum* J. Ag.	D	37.36	2.49	161.18	15.0	599:34:1
		P	36.91	2.29	147.72	16.1	645:34:1
		O	35.78	2.15	136.87	16.6	675:35:1
13.	*Cystoseira indica* (Thivy *et* Doshi) Mairh	D	32.00	2.03	135.39	15.7	610:33:1
		P	31.20	1.86	123.47	16.8	652:33:1
		O	32.37	1.91	140.16	16.8	597:30:1
14.	*Sargassum johnstonii* Setchell and Gardner	O	32.17	1.79	108.05	18.0	769:37:1
15.	*S. swartzii* (Turn) C. Ag.	P	29.73	1.80	118.39	16.5	648:33:1
		O	32.71	2.04	127.83	16.0	661:35:1
16.	*S. tenerrimum* J. Ag.	D	30.01	1.99	102.03	15.1	760:43:1
		P	30.30	2.20	94.65	13.8	823:51:1
		O	29.70	2.12	85.78	14.0	894:55:1
	Mean of brown seaweeds		32.26 ± 3.17	2.01 ± 0.20	126.58 ± 19.20	16.05 ± 1.07	35.84 ± 6.87 (N/P atomic ratio)

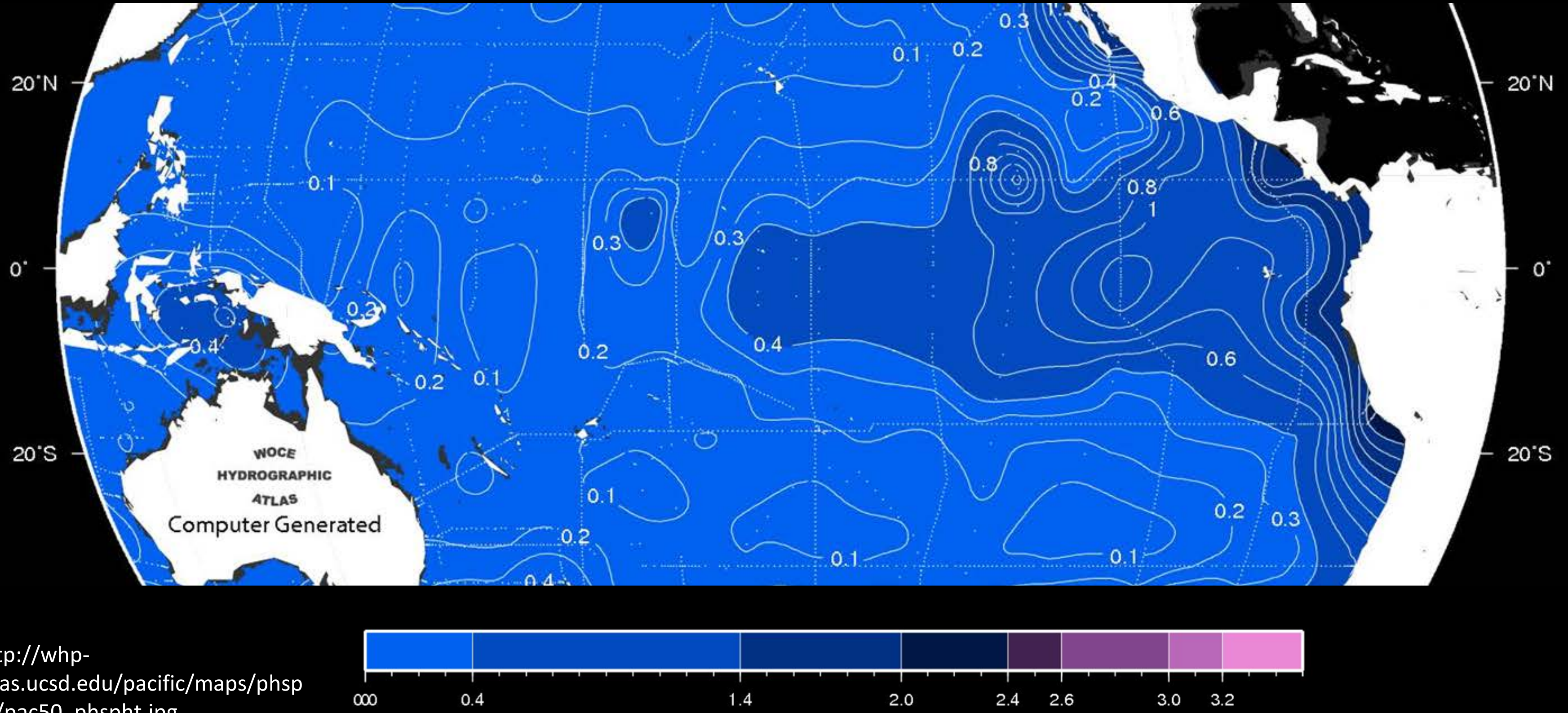
Macroalgae all have super Redfield Ratios of 220:1 up to 800:1 for C:P

Rao, C. and Indusekhar, V., 1987. *Carbon, nitrogen and phosphorus ratios in seawater and seaweeds of Saurashtra, north west coast of India*.

Example Solution: Marine Permaculture



Phosphate levels (µmol/kg) at 50 m across equatorial Pacific



http://whp-atlas.ucsd.edu/pacific/maps/phspht/pac50_phspht.jpg

Long-term vision: Venerable Kelp cutters & at-sea biorefineries harvesting and processing a thousand tons per day

San Diego History Center, Balboa Park, San Diego, California 92101
(http://www.sandiegohistory.org/)

At-Sea Biorefinery -->
Food, Fuel, Feed, and Fertilizer

Source: Shell Prelude FLNG
https://www.shell.com/energy-and-innovation/natural-gas/floating-lng.html

Role of macroalgae in carbon sequestration

Median Time to water outcropping from 1000 meters approaches 1000 years

(England, M. (1995). The age of water and ventilation timescales in a global ocean model. Journal of Physical Oceanography, 25(11), 2756-2777.)

CO_2 negatively buoyant below 3000m

Permanent storage possible in porous sea-floors

(House, K.Z., Schrag, D.P., Harvey, C.F. & Lackner, K.S. (2006). Permanent carbon dioxide storage in deep-sea sediments. Proceedings of the National Academy of Sciences of the United States of America, 103(11), 12291-12295)

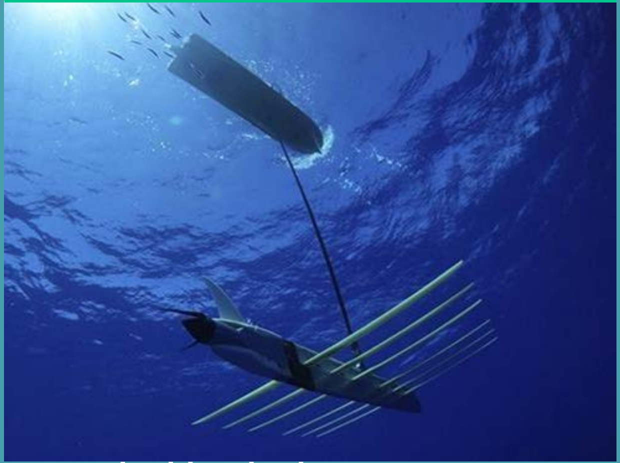
Source: Gilbert T. Rowe and Nick Staresinic (1979)

Measuring Blue Carbon

Sediment traps

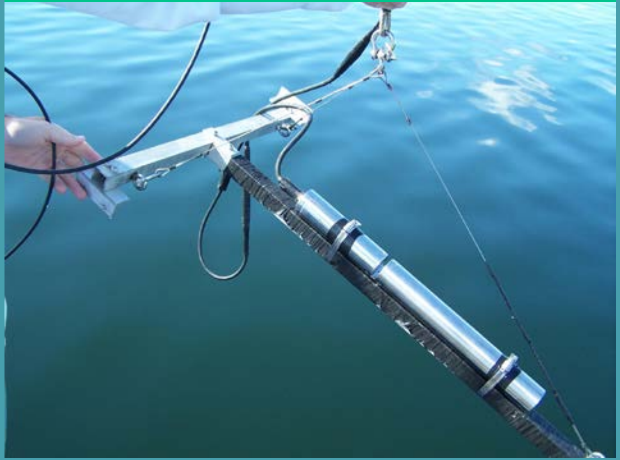
Monterey Bay Aquarium Research Institute

Undersea drones for measurements



Liquid Robotics' Wave Glider

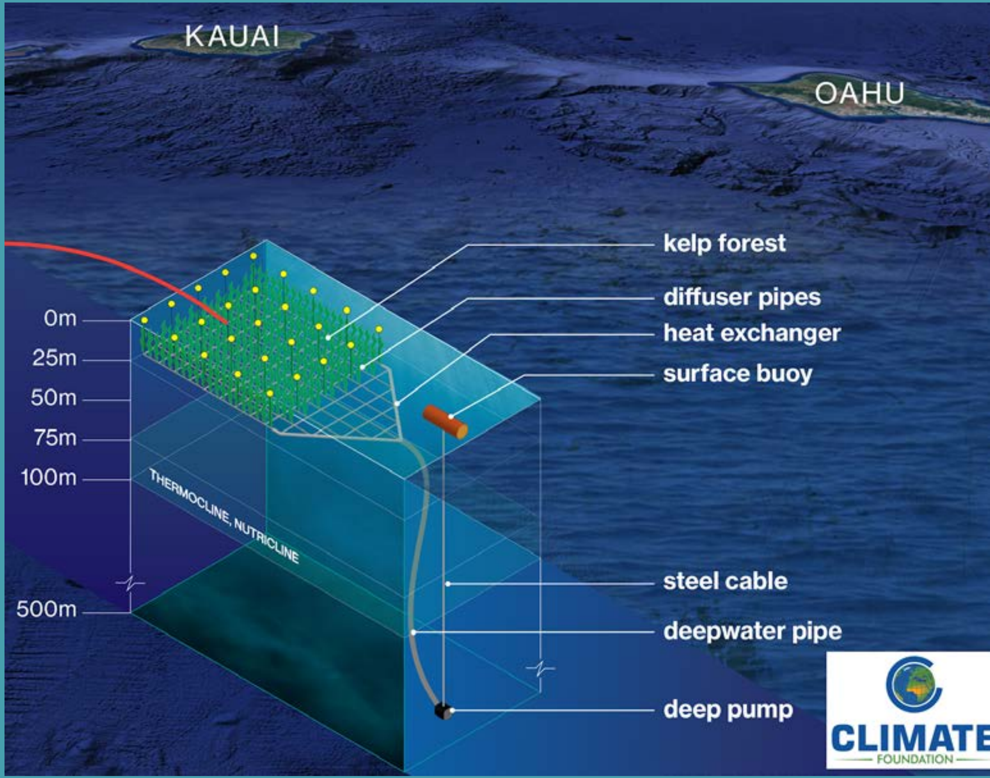
Real time environmental measurements of temperature and biogeochemical signals



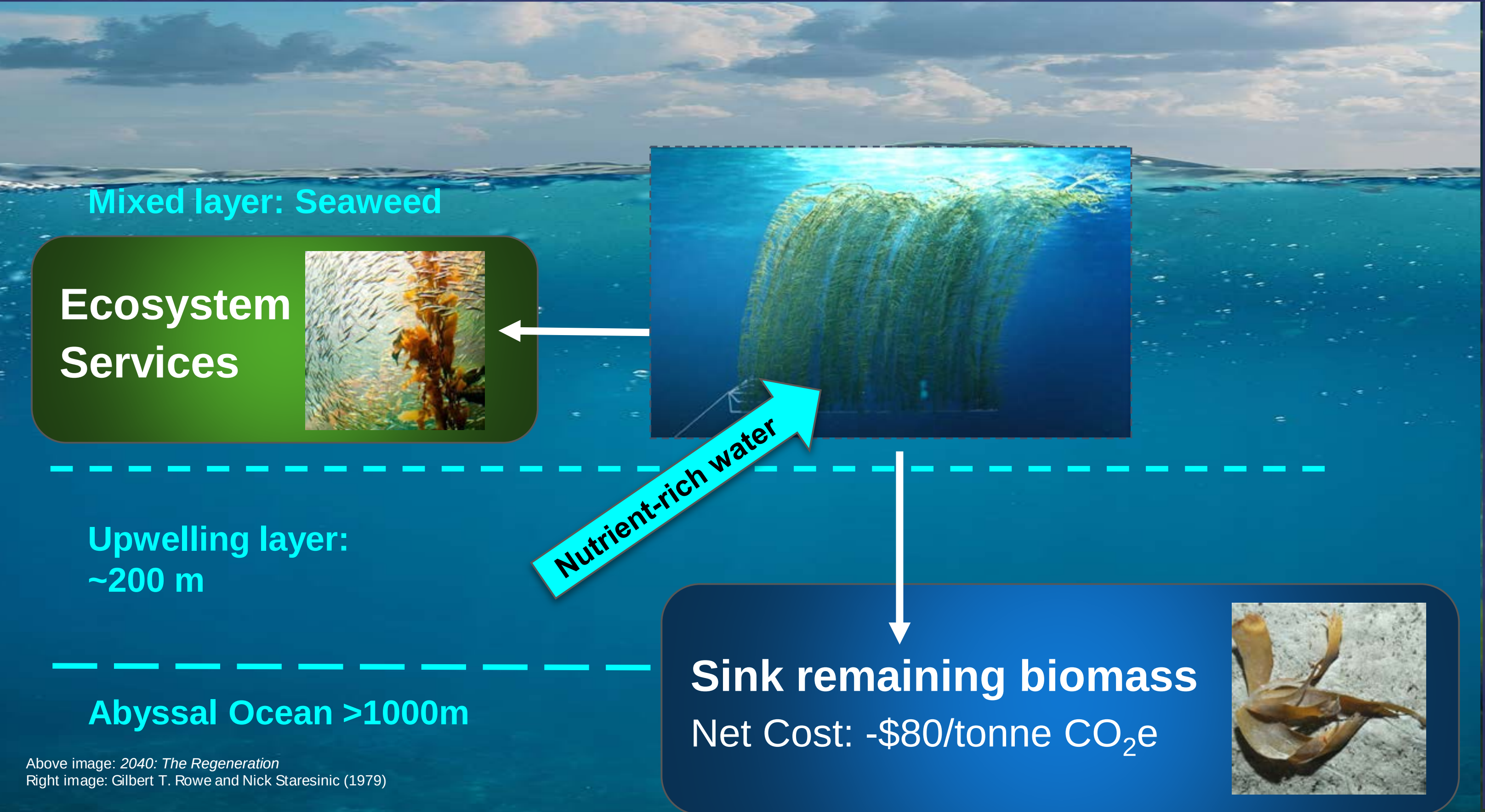
Sea-Bird Scientific

Marine Permaculture

- 1 dry (~30% moisture) ton seaweed=1 ton CO_2.
- 2,000 to 10,000 dry tons/km^2/yr under marine permaculture.
- Food, feed and industrial products pay for the carbon sink.
    - 0.7 gigaton feed supplement
    - 0.5 gigaton fish habitat
    - 0.3 gigaton food / fertilizer



Marine Permaculture



Above image: *2040: The Regeneration*
Right image: Gilbert T. Rowe and Nick Staresinic (1979)

CLIMATE FOUNDATION

Marine Permaculture

Mixed layer: Seaweed

Ecosystem Services

Nutrient-rich water

Commercial Uses

Upwelling layer:
~200 m

Sink remaining biomass

Net Cost: -\$80/tonne CO_2e

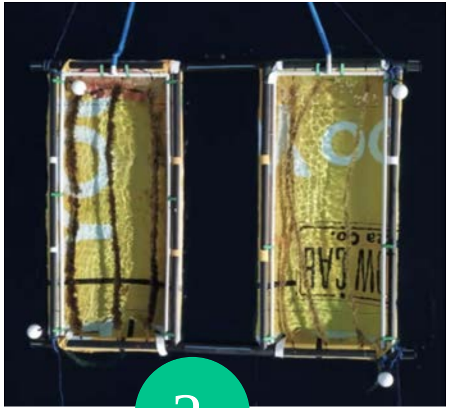
Abyssal Ocean >1000m

Above image: *2040: The Regeneration*
Right image: Gilbert T. Rowe and Nick Staresinic (1979)

Our Innovation & Technology Roadmap

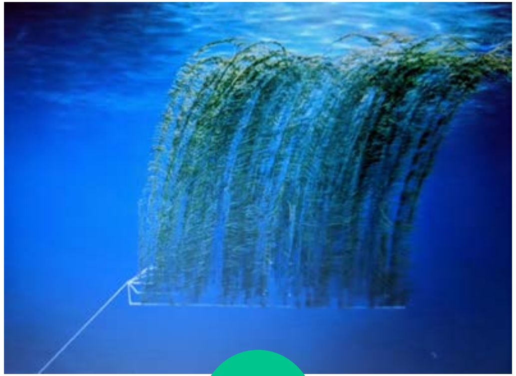
1

Phase I: completed upwelling testing



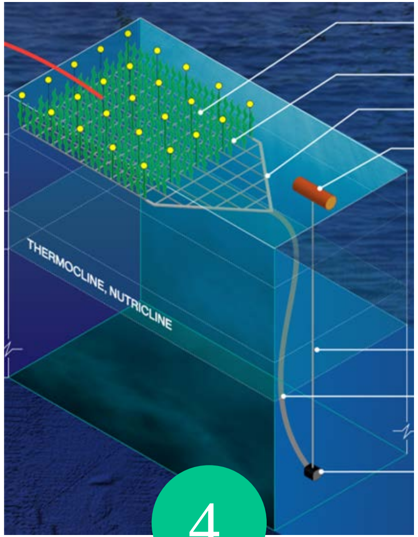
2

Phase II: trough-based system, algae growth analysis, patent applications,
Blue Economy Challenge



3

Phase III: Hectare-scale MPA,
Self-guided ocean vessels,
Pilot Project Initiatives



4

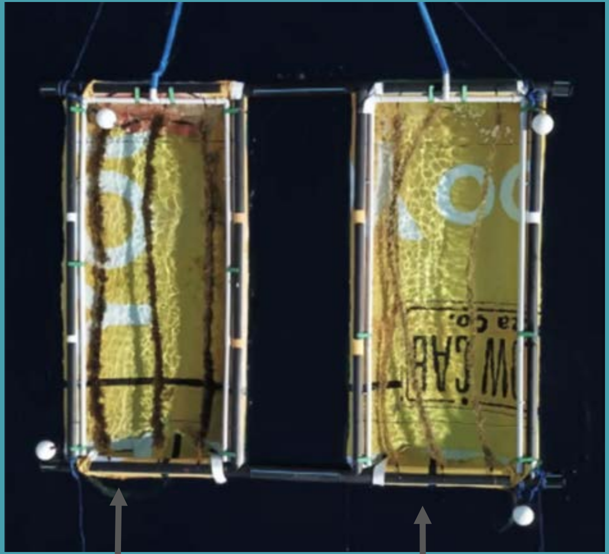
Phase IV:
100-hectare MPA,
Patent-pending
Enhanced Technology

2009-2013 | 2015-2020 | 2020-2022 | 2022+

CLIMATE FOUNDATION

Pipe-based MP upwelling system

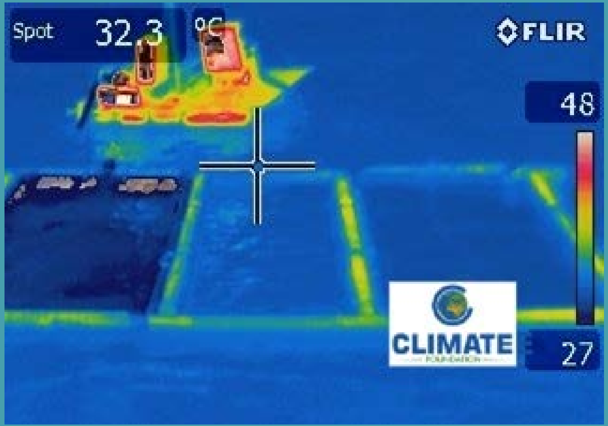
Trough based MP upwelling system



Deep seawater Irrigation

Surface water Irrigation

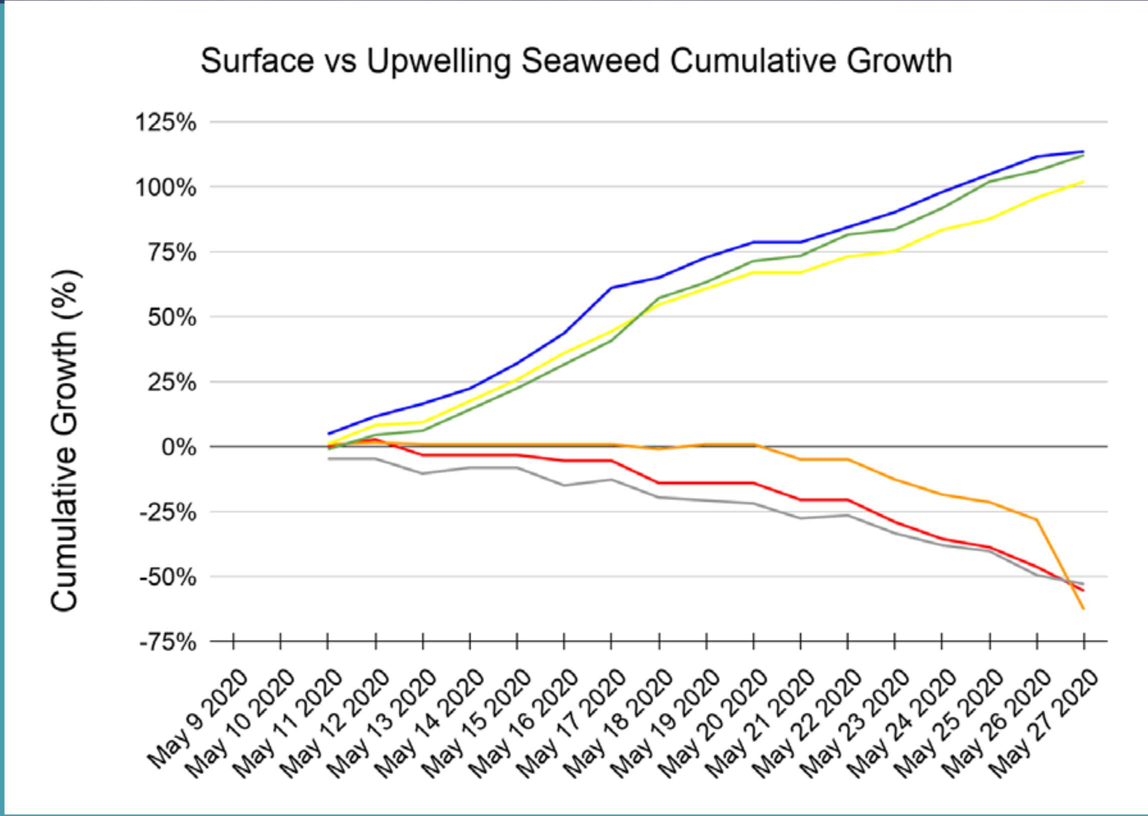
Thermal image of the troughs



Dark are irrigated
Light are ocean temperature

Returning sardine populations to Cebu

CF Upwelling growth trials: Philippines, May 2020



Kappaphycus **grown with: Surface water: Orange, red, grey; Upwelled water: blue, green, yellow**

Regenerating Giant Kelp in Tasmania

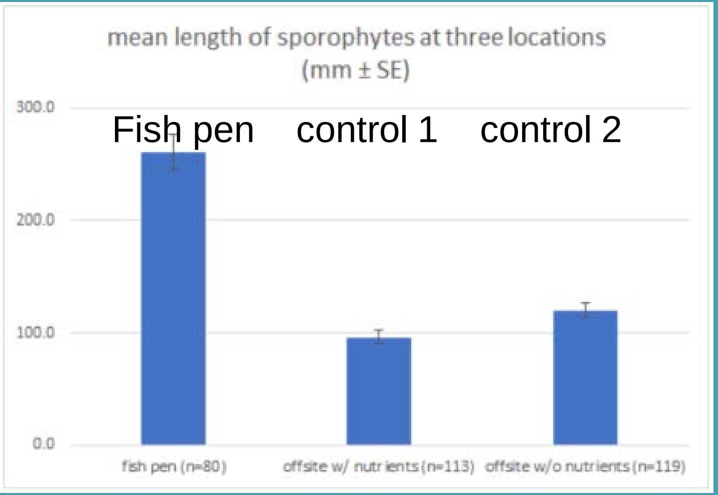
Sporophytes

Juveniles

Mature Kelp

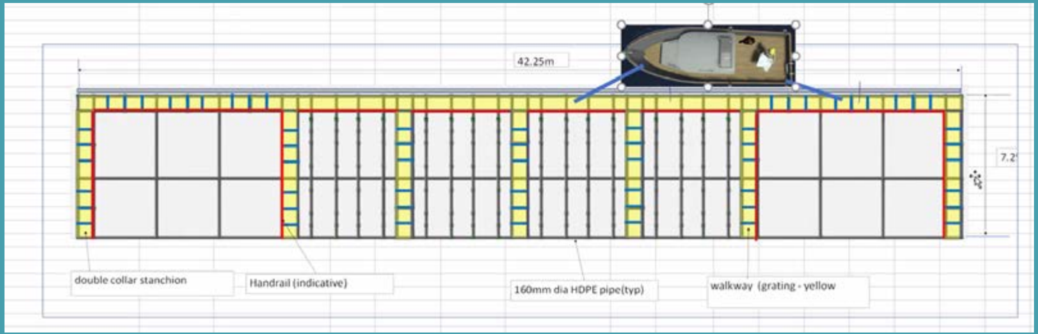
Australia/Tasmania project Phase 1

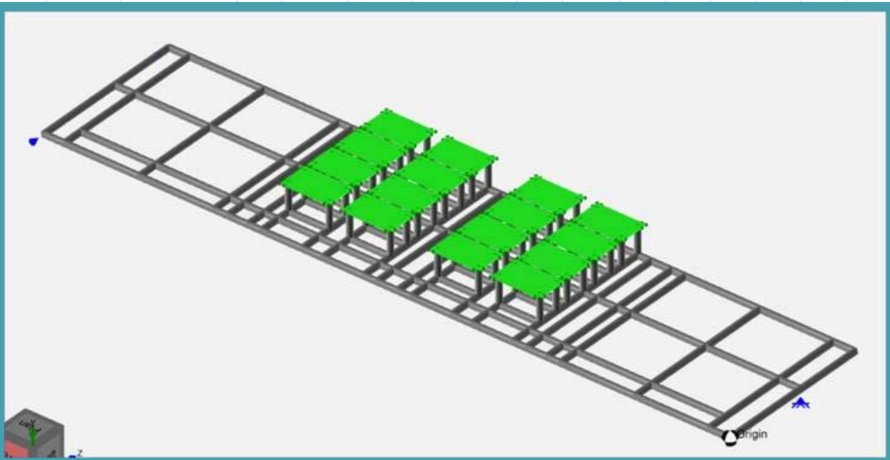
Left: Offshore salmon aquaculture pens (photo by Huon Aquaculture)
Right: Giant kelp growing on outplanted lines. Credit, Cayne Layton, IMAS, UTAS

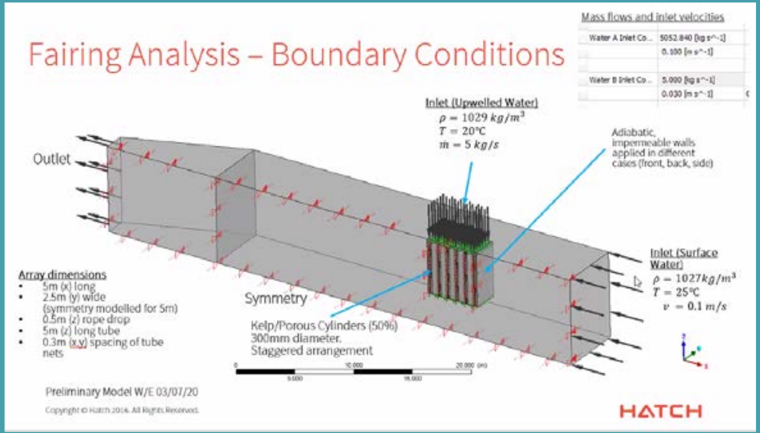


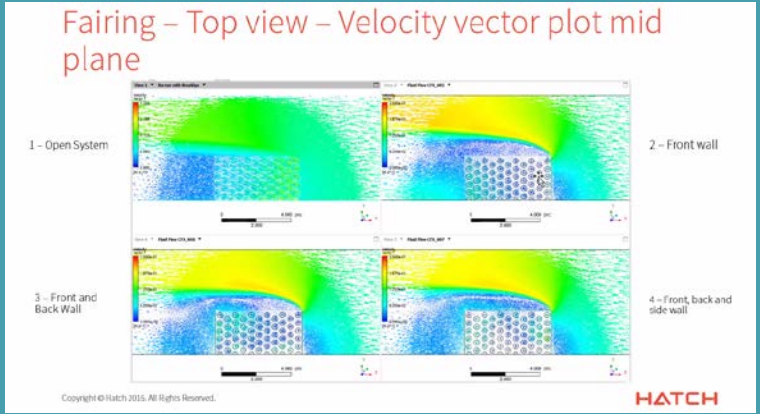
- Kelp planted out in Storm Bay grown.
- Higher nutrient levels rescued kelp production, whereas warm-tolerant genotypes alone may not rescue production.
- Kelp near the fish cages are >10.0m long, while the control is just 2.5m

Hatch EPCM Engineering Services Design and Modelling Work









Images credit: Hatch 2020

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J.J. Polvina, E.A Howell, M. Abecassis. (2008). Ocean’s least productive waters are expanding. *Geophysical Research Letters*. https://doi.org/10.1029/2007GL031745

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Key topics to discuss

- Discuss the use of phosphate measurements to track net carbon sequestration.

- Discuss the recognition & development of macroalgae as a blue carbon sink.

- Accelerate investment for offshore research & development trials to enable at-scale cultivation, harvesting and carbon methodologies.

Thank you!

Questions are welcome.

Prospective supporters are invited to contact us:

info@climatefoundation.org

Executive Summary available upon request.

FATE OF MACROALGAE IN THE NATURAL HABITAT

Dorte Krause-Jensen

Dept. of Bioscience & Arctic Research Centre, Aarhus University

Based on collaboration with a dream team of colleagues

THE NATIONAL ACADEMIES OF SCIENCE, ENGINEERING AND MEDICINE'S WORKSHOP ON OCEAN-BASED CDR OPPORTUNITIES AND CHALLENGES - PART 3: ECOSYSTEM RECOVERY & SEAWEED CULTIVATION

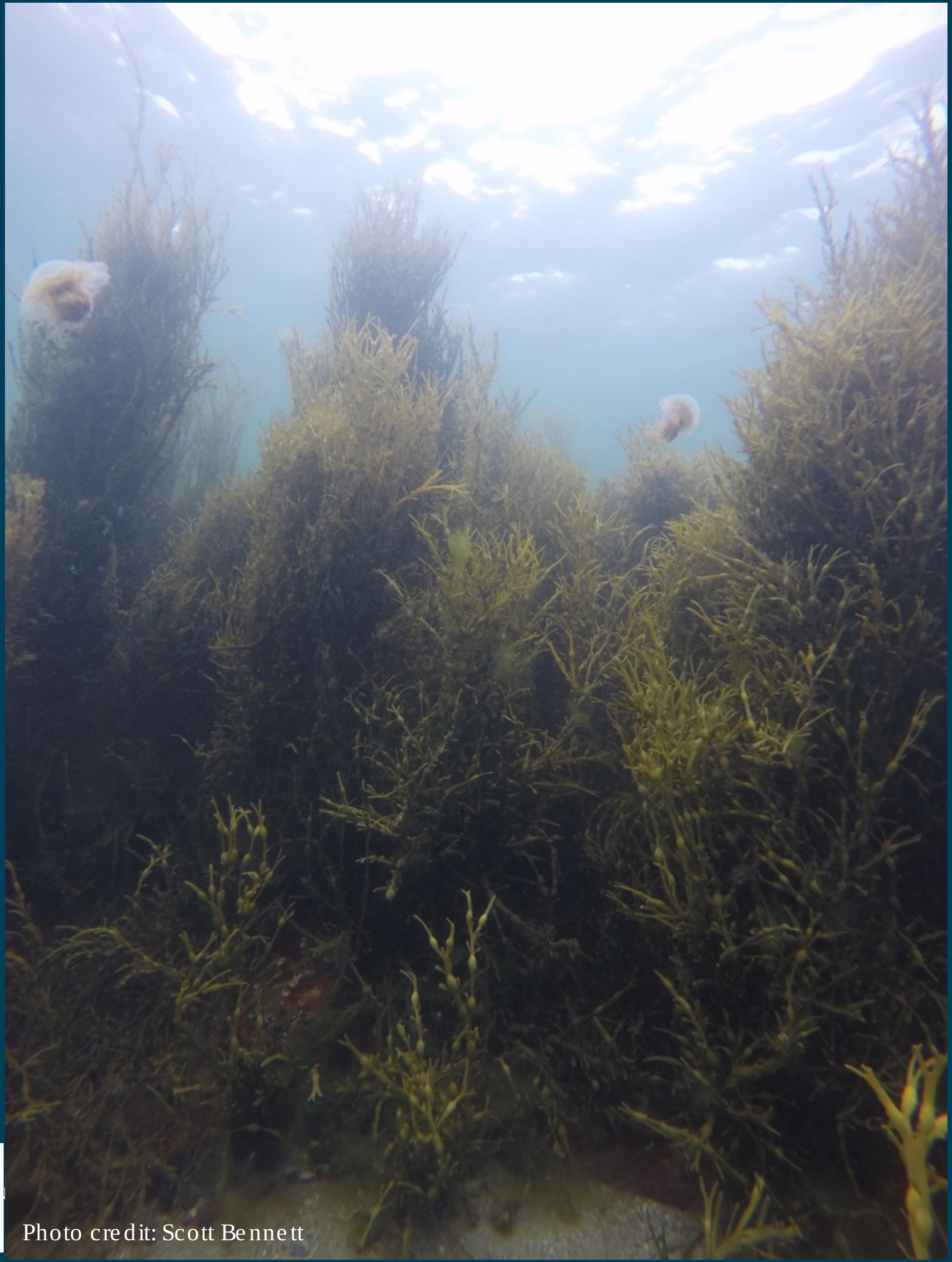
EUROMARINE

ON-LINE, FEBRUARY 2, 2021

AARHUS UNIVERSITY
DEPARTMENT OF BIOSCIENCE

INDEPENDENT RESEARCH FUND DENMARK

Future MARES



GLOBAL MACROALGAL EXTENT AND PRODUCTIVITY

Diverse group - huge habitat variability

Uncertain global estimates (mean of compiled estimates: Krause-Jensen & Duarte 2016):

Area: 3.54 million km^2

Productivity: 1521 TgC yr^{-1}

Updates underway (Duarte et al. submittted)!

Map by J. Assis as preparation for Duarte et al. submitted.

Photo: Scott Bennett

Photo: Peter Bondo

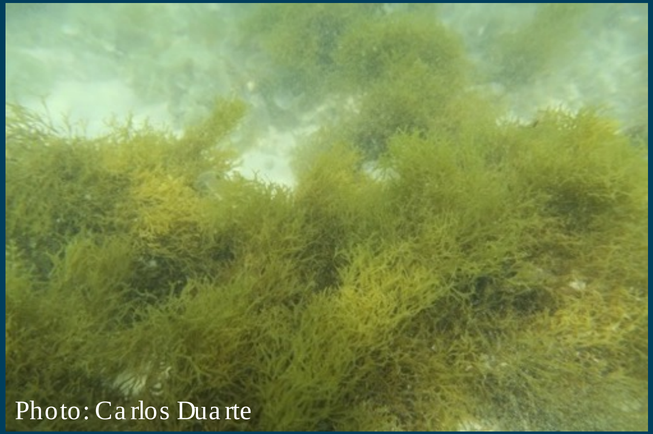
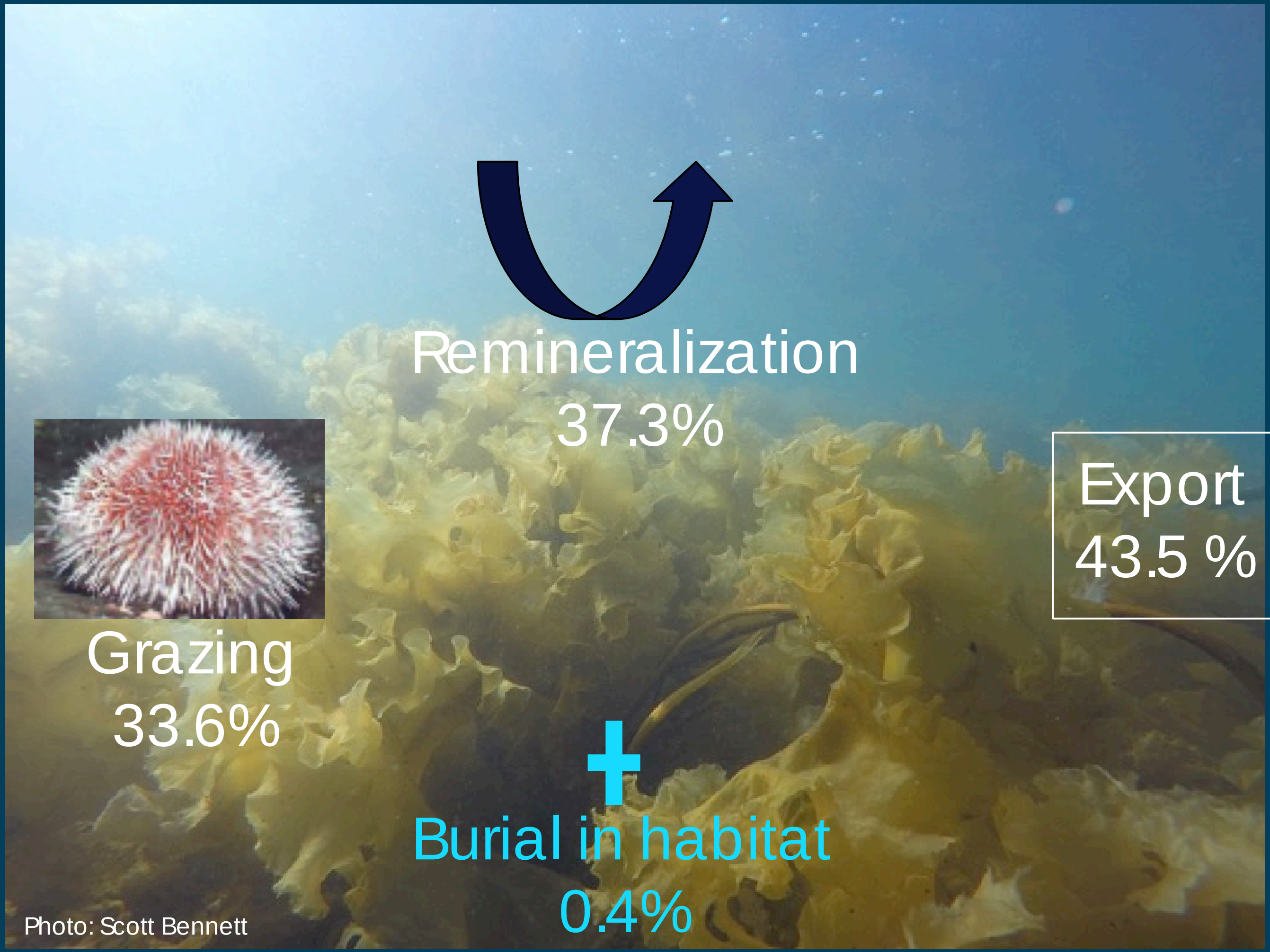


Photo: Carlos Duarte

Photo: Ryan Murphy

From Baker 2017. Deep Sea Research

FATE OF MACROALGAL PRODUCTION

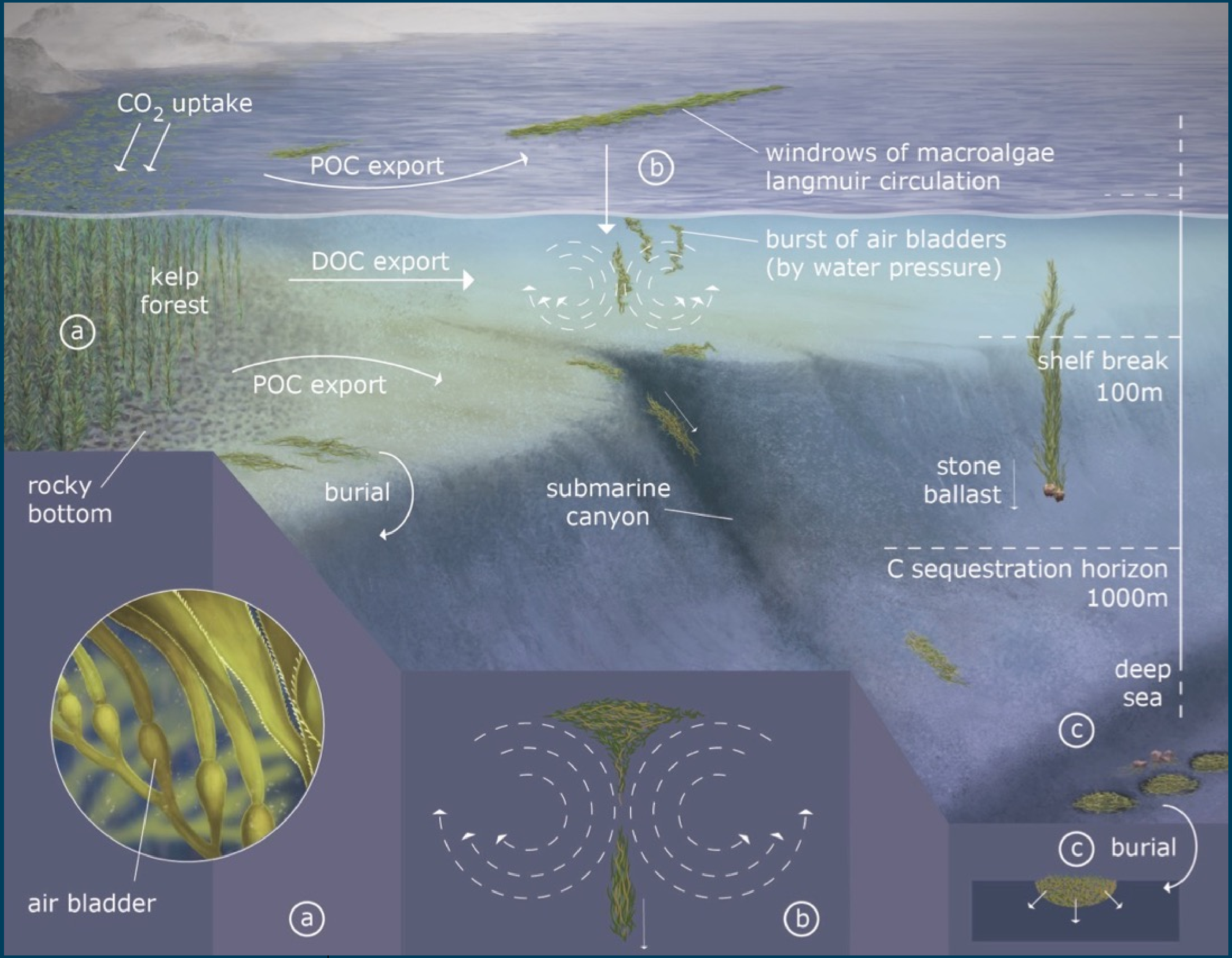


Export
43.5 %

Budget from Duarte & Cébrian 1996. Limnol. Oceanogr.

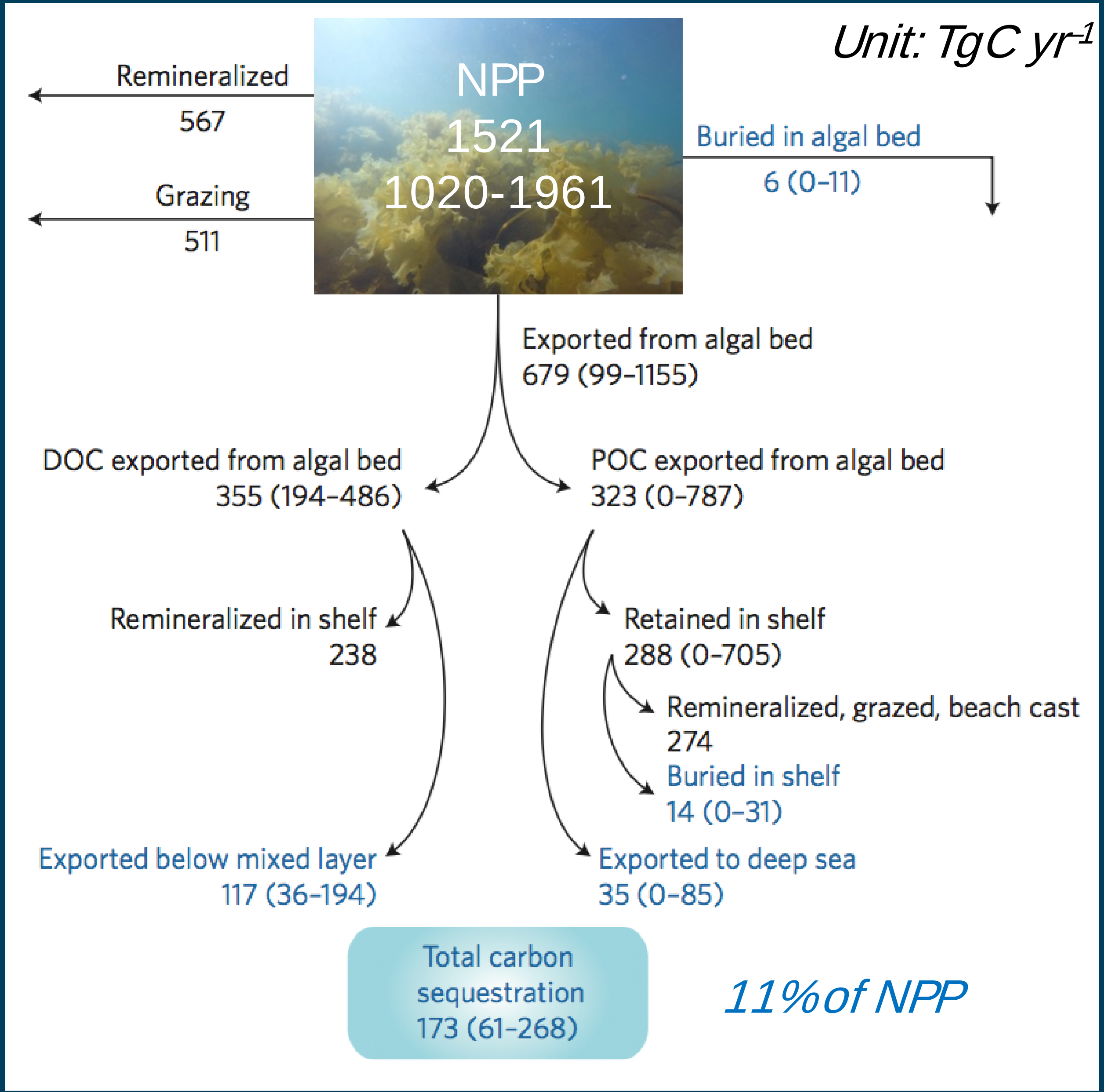
To blue Carbon sinks beyond the habitat?

PATHWAYS FOR C-SEQUESTRATION



Krause-Jensen & Duarte 2016. Nature Geoscience

1ST ORDER GLOBAL MACROALGAL C-SEQUESTRATION ESTIMATE



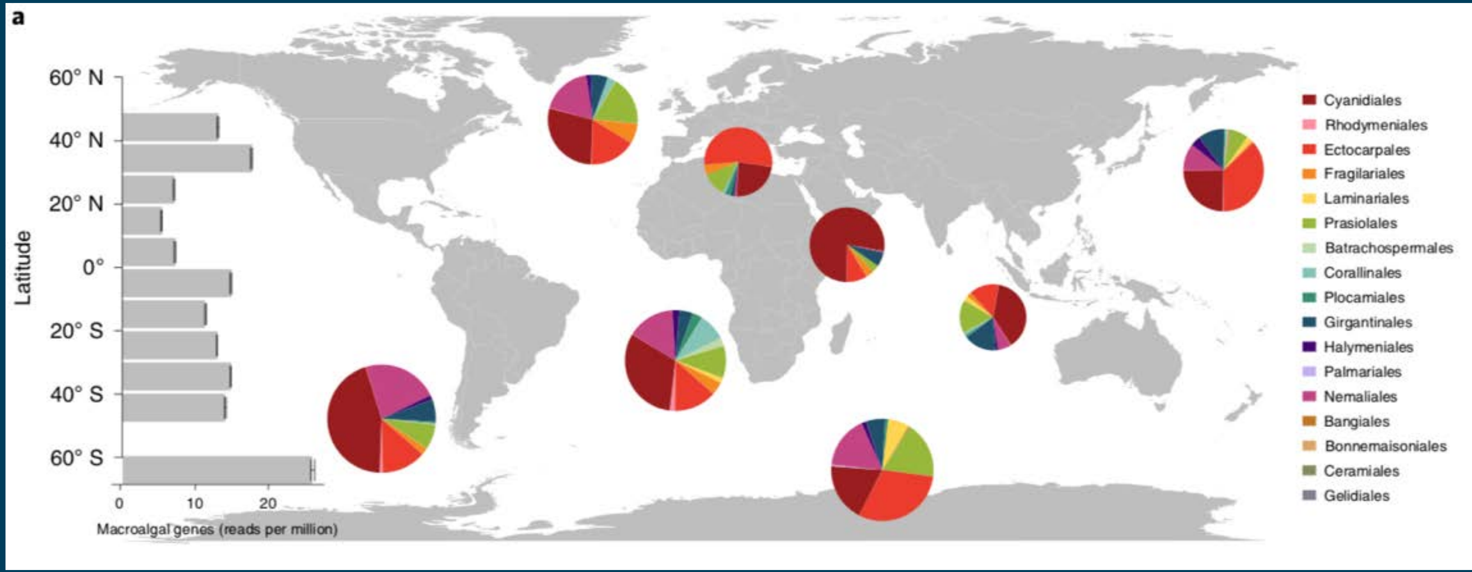
Krause-Jensen & Duarte 2016. Nature Geoscience

Ongoing research focus on:

- Macroalgal C-fluxes (POC, DOC), recalcitrance, fate and tracing
- Effects of traits and habitat type on C-fluxes and sequestration
- Inclusion of in global C-budgets
- Changes in habitats and potential for BC management

Euromarine foresight workshop on the role of macroalgae in the global ocean carbon budget; 2019

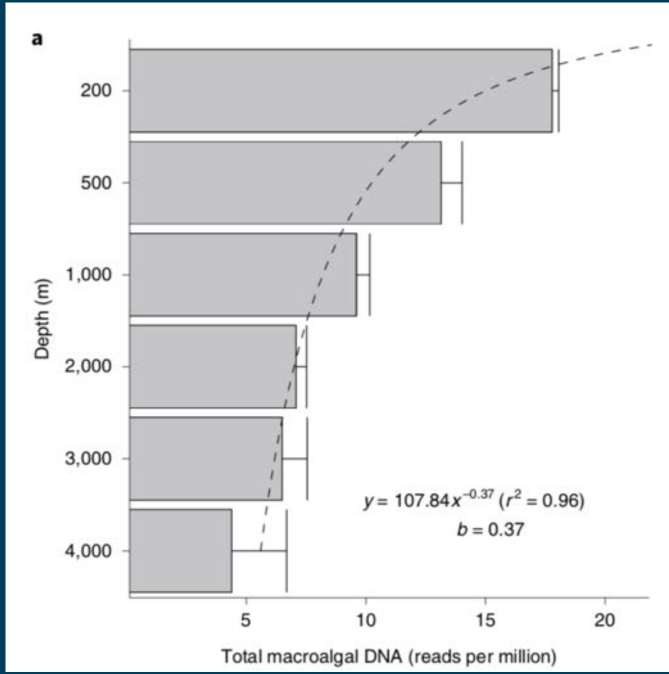
MACROALGAL GENES ACROSS THE GLOBAL OCEAN

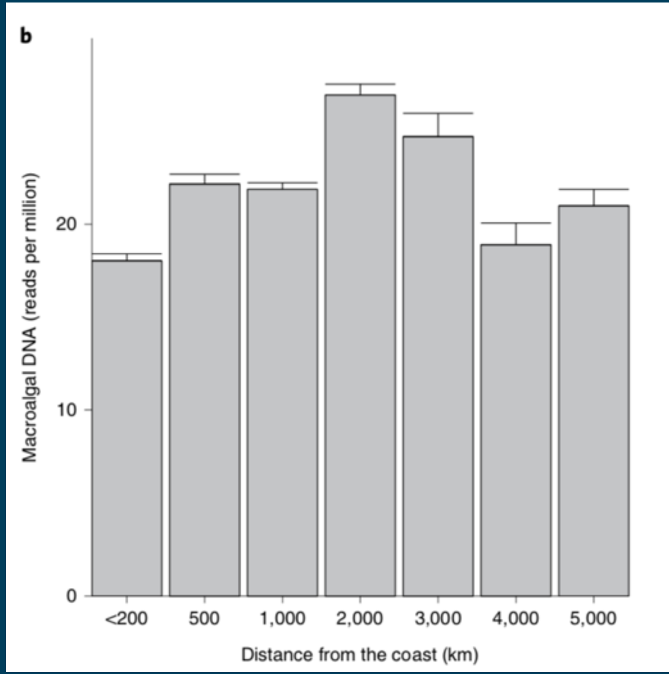


Global genome data set shows macroalgal genes in water column across latitudes, depth gradients and at distance from coast

-> underpins major role of macroalgae in C-sequestration

Ortega et al 2019. Nature Geoscience

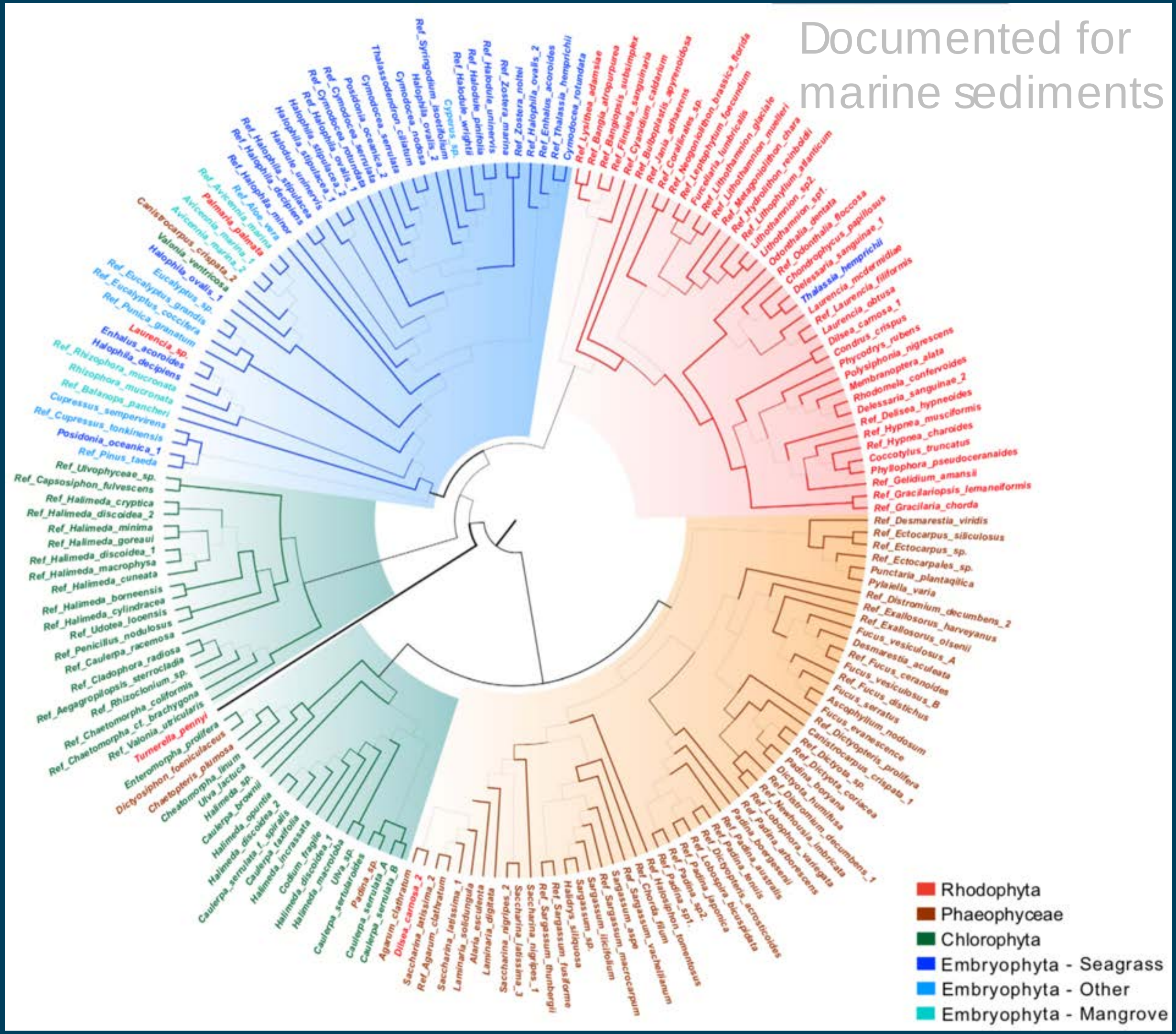




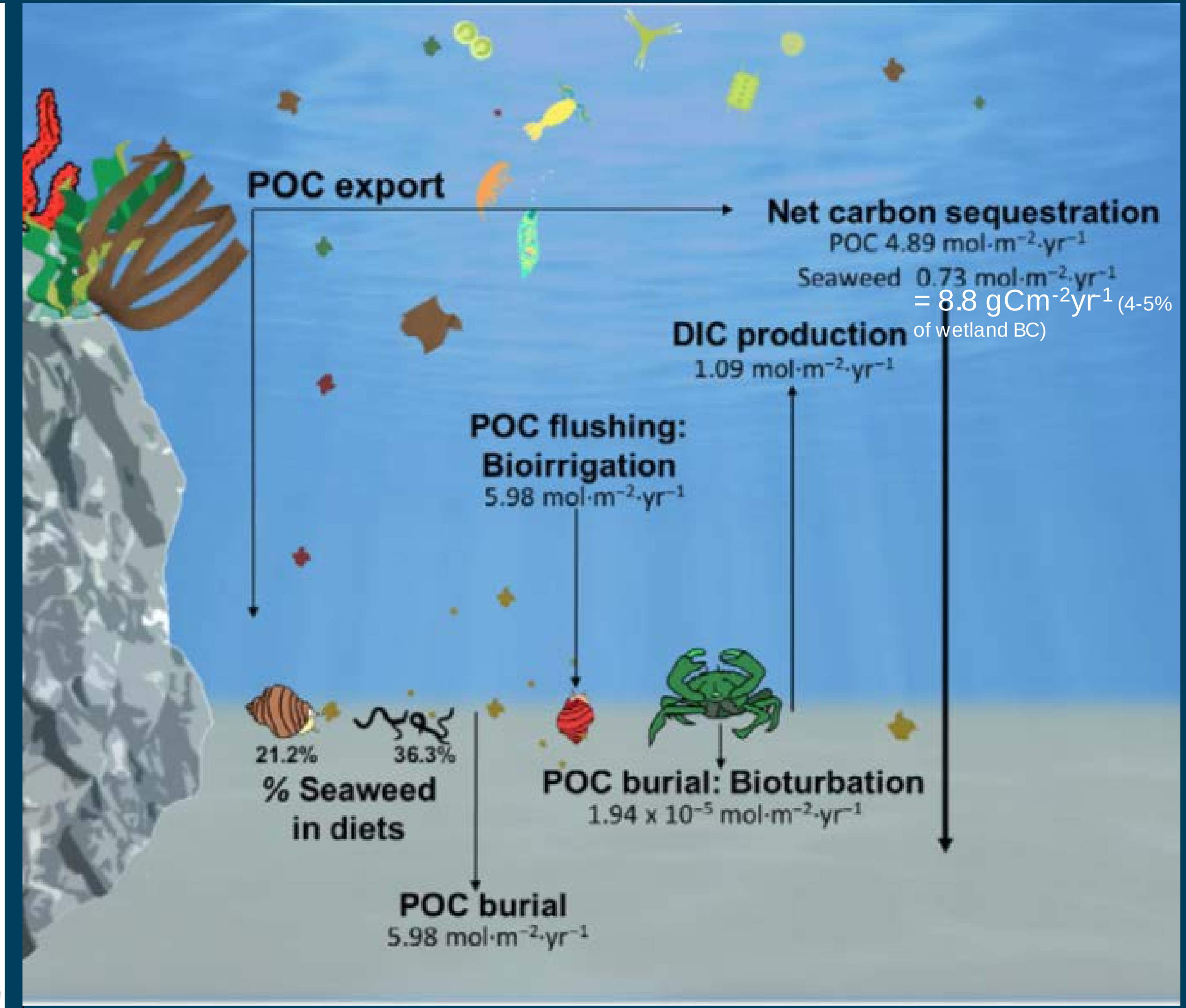
FIELD EVIDENCE OF MACROALGAL C-SEQUESTRATION VIA E-DNA

A DNA (18S rRNA) minibar code & ref. library for marine macrophytes. -> Boreal/ Arctic counterpart underway

Documentation of macroalgae in offshore sediments by eDNA and stable isotopes

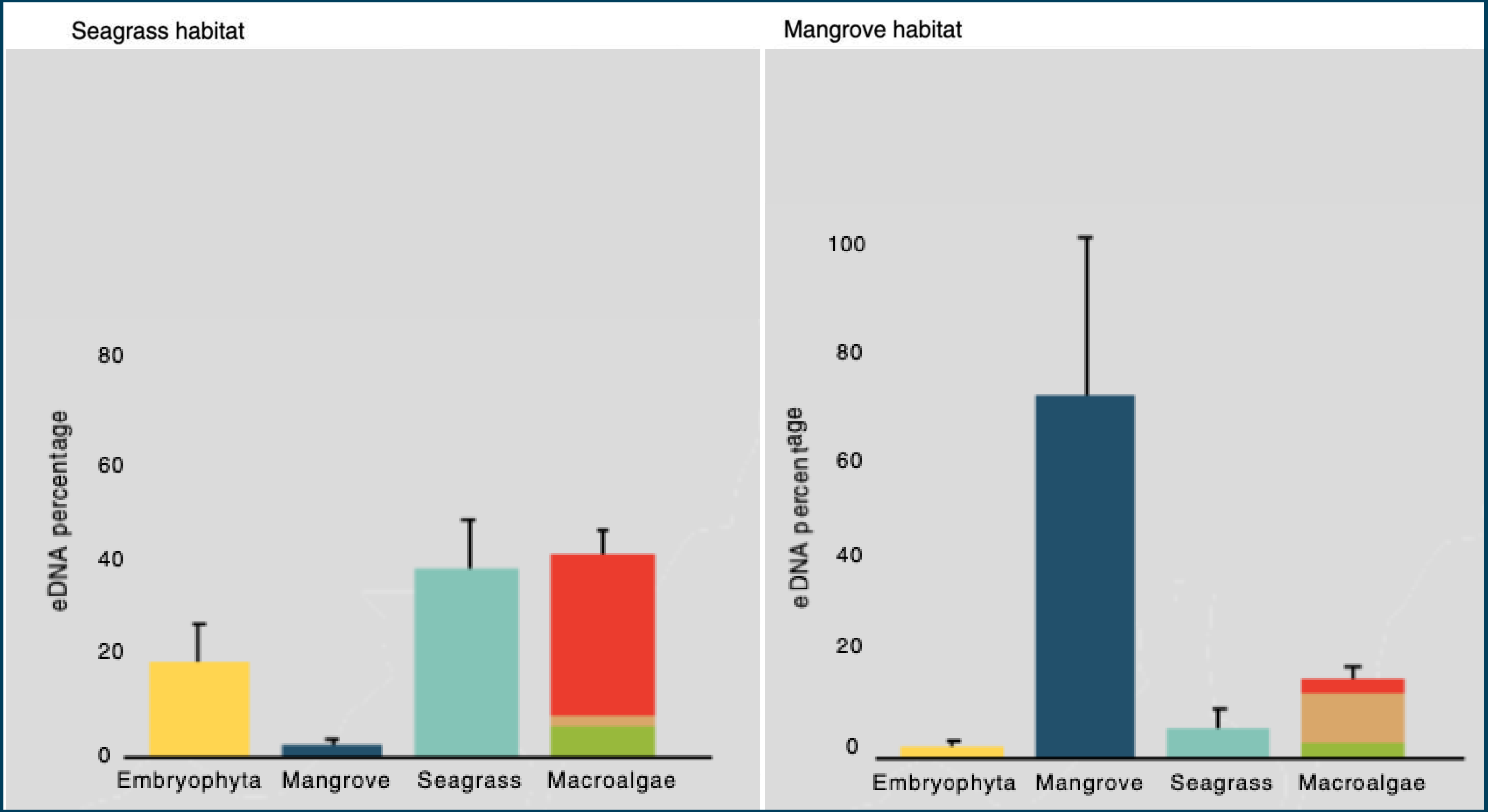


Ortega et al. 2020 Molecular Ecology Resources. Ørberg et al. submitted.



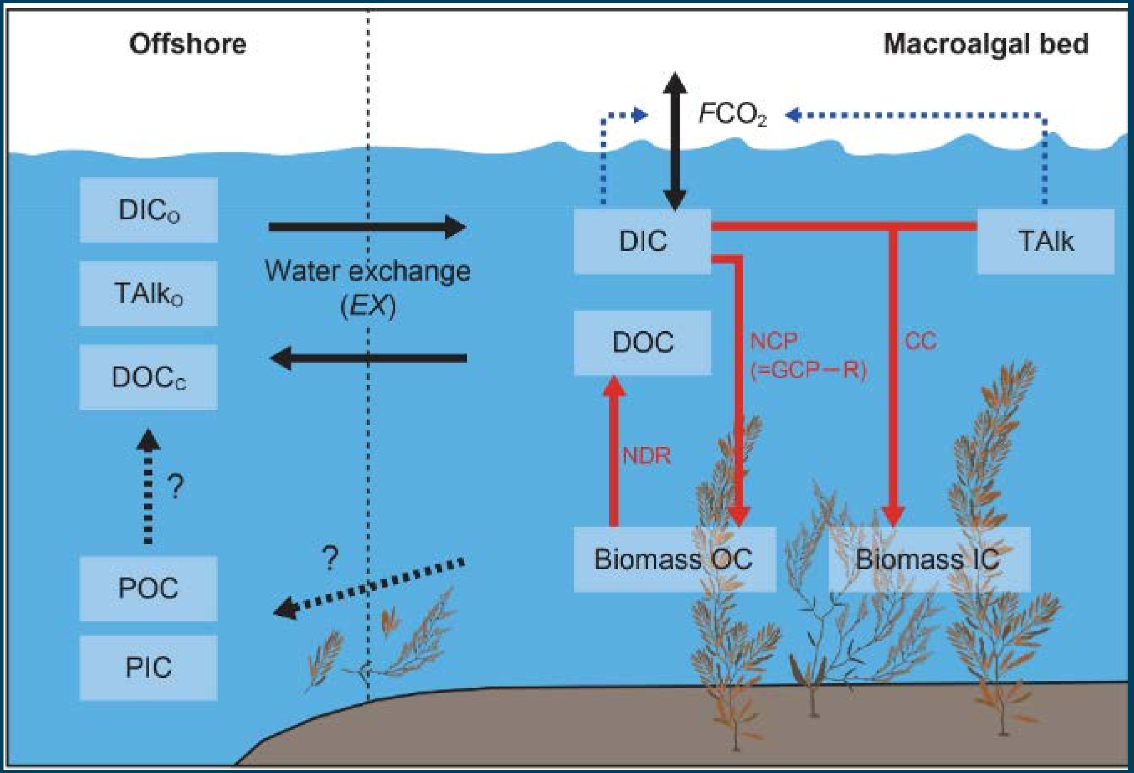
Queiros et al. 2019. Ecological Monograph

MACROALGAL CONTRIBUTION TO SEDIMENT EDNA



Ortega et al 2020. Limnol. Oceanogr.

UPDATES ON MACROALGAL DOC EXPORT



Watanabe et al 2020. Biogeosciences.

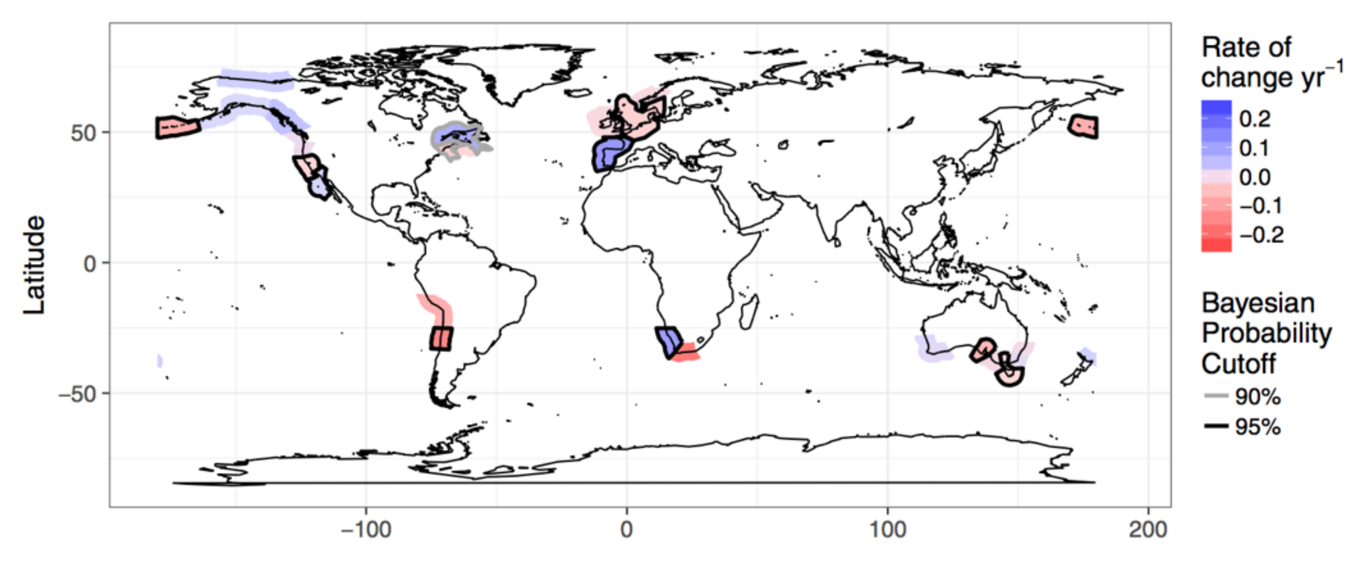
Example from Japanese Sargassum beds

- Create significant CO_2 sinks around them
- export 6-35% of NCP offshore as DOC
- 56-78% of DOC is refractory (>150 d)

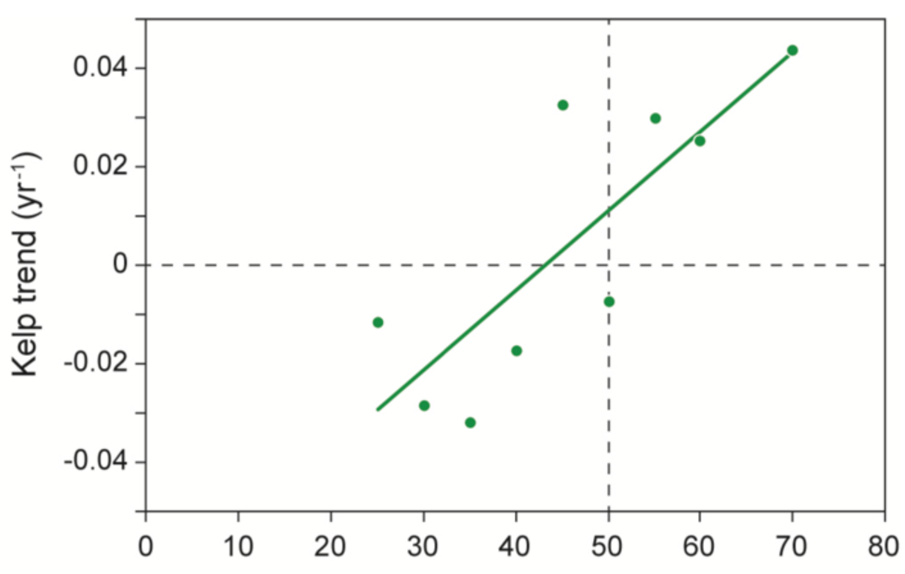
Need for further large-scale asssessment

RELEVANCE FOR CC MITIGATION DEPENDS ON TRENDS IN AREA

TRENDS IN GLOBAL KELP AREA



Krumhansl et al. 2016



Duarte et al. submitted

Local trends dominate dynamics, no clear global trends

Tendency for increasing trends at high lat.

CONCLUSION AND PERSPECTIVES

- Macroalgae form the most extended BC habitats
- Research agenda for improved estimates of macroalgal area/ trends, DOC/ POC-fluxes & sequestration -> to refine macroalgal C-budgets and to assess potentials for CC mitigation via protection/ restoration of habitats and sinks
- The inherent challenge to link macroalgal C-sinks to specific habitats makes it problematic to verify C-capture by protection/ restoration of wild macroalgal habitats

For suggested research/ management agenda, see also Krause-Jensen et al. 2018. Biol. Letters


Photo credit: Peter Bondo Christensen

BREAK

We will resume at 2:30pm EST

Benthic macroalgal contributions to ocean carbon dioxide removal

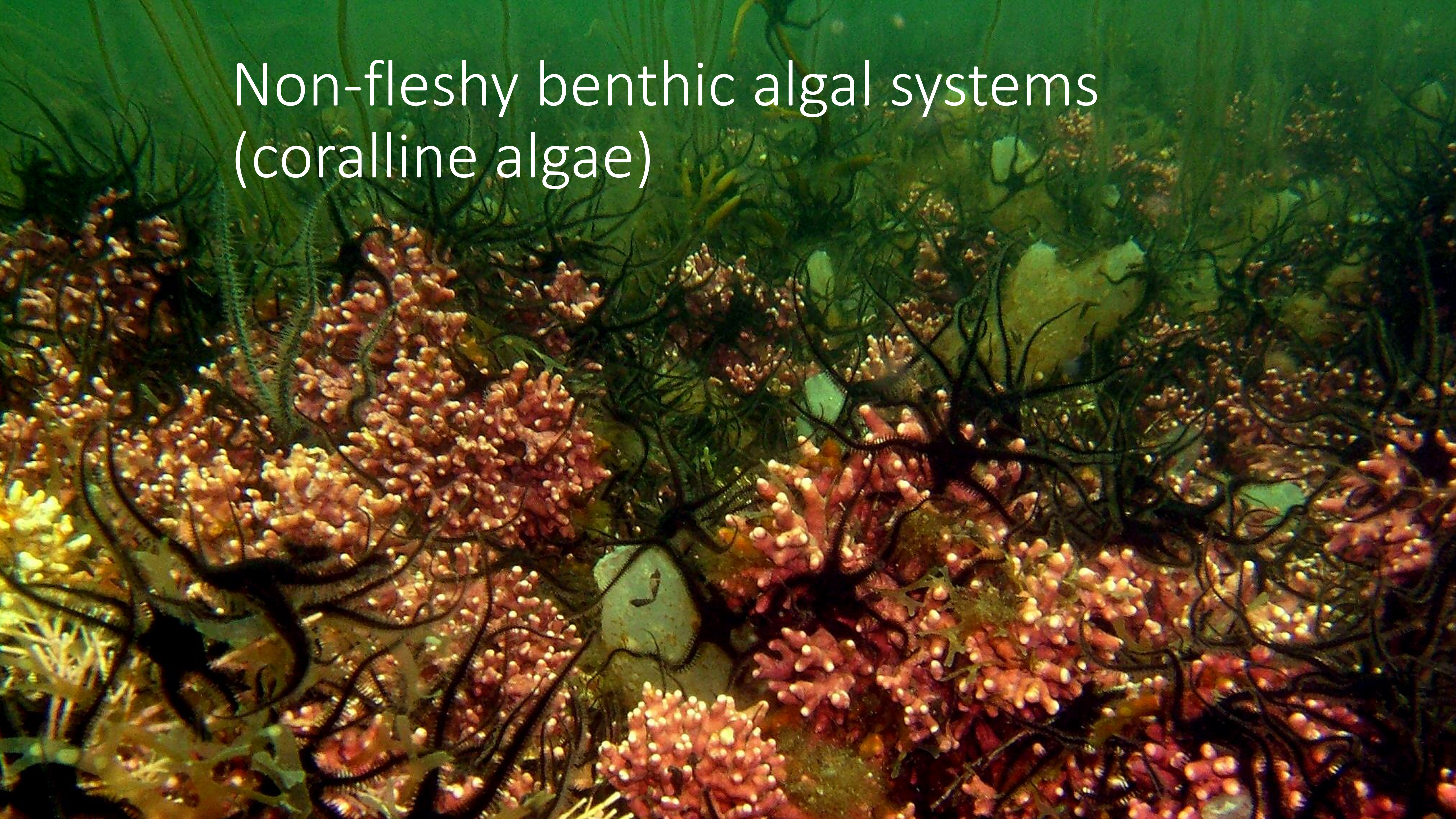
Dr Nick Kamenos

University of Glasgow, Scotland

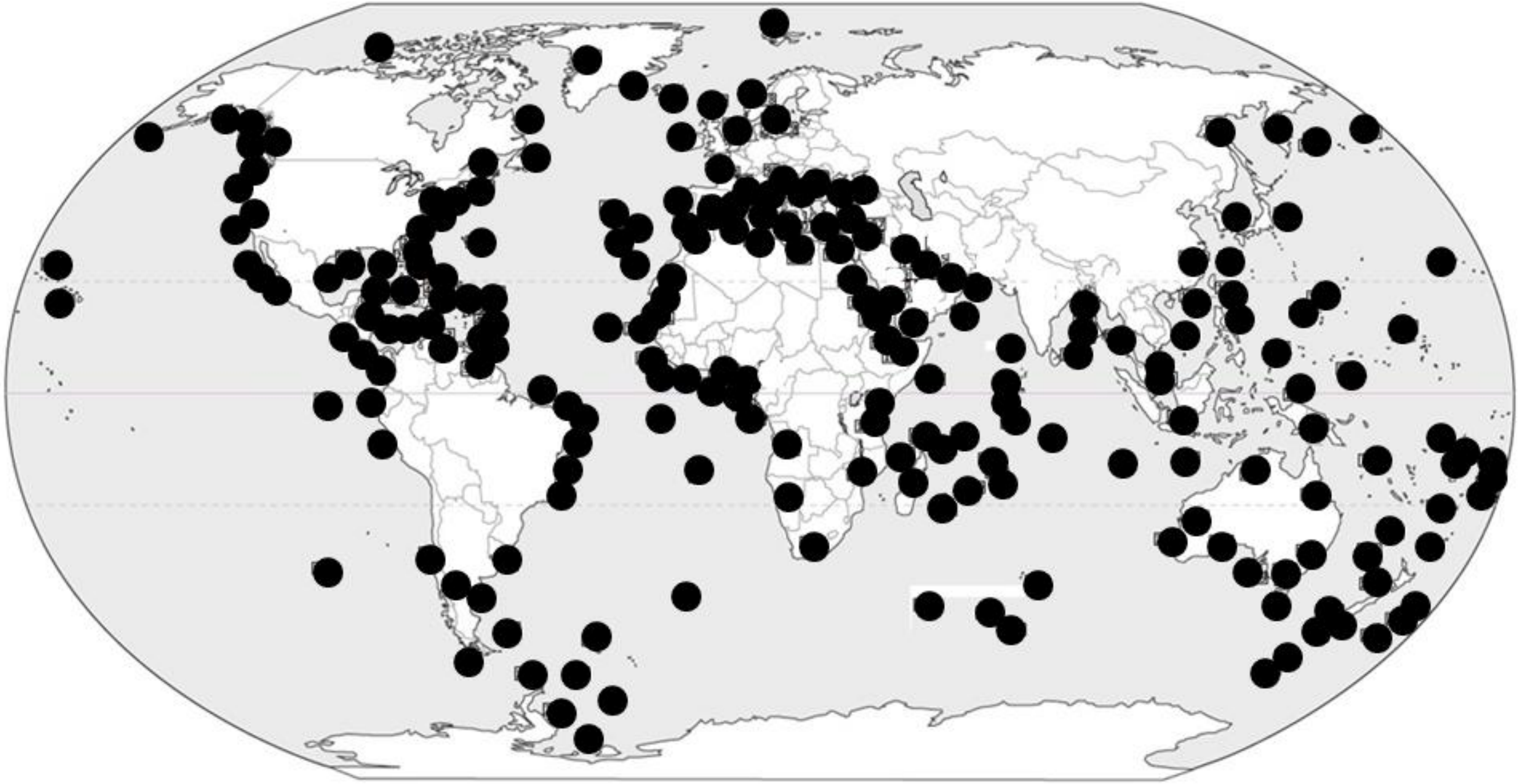
National Academy of Sciences, Engineering and Medicine (USA)

2nd February 2021

Non-fleshy benthic algal systems (coralline algae)



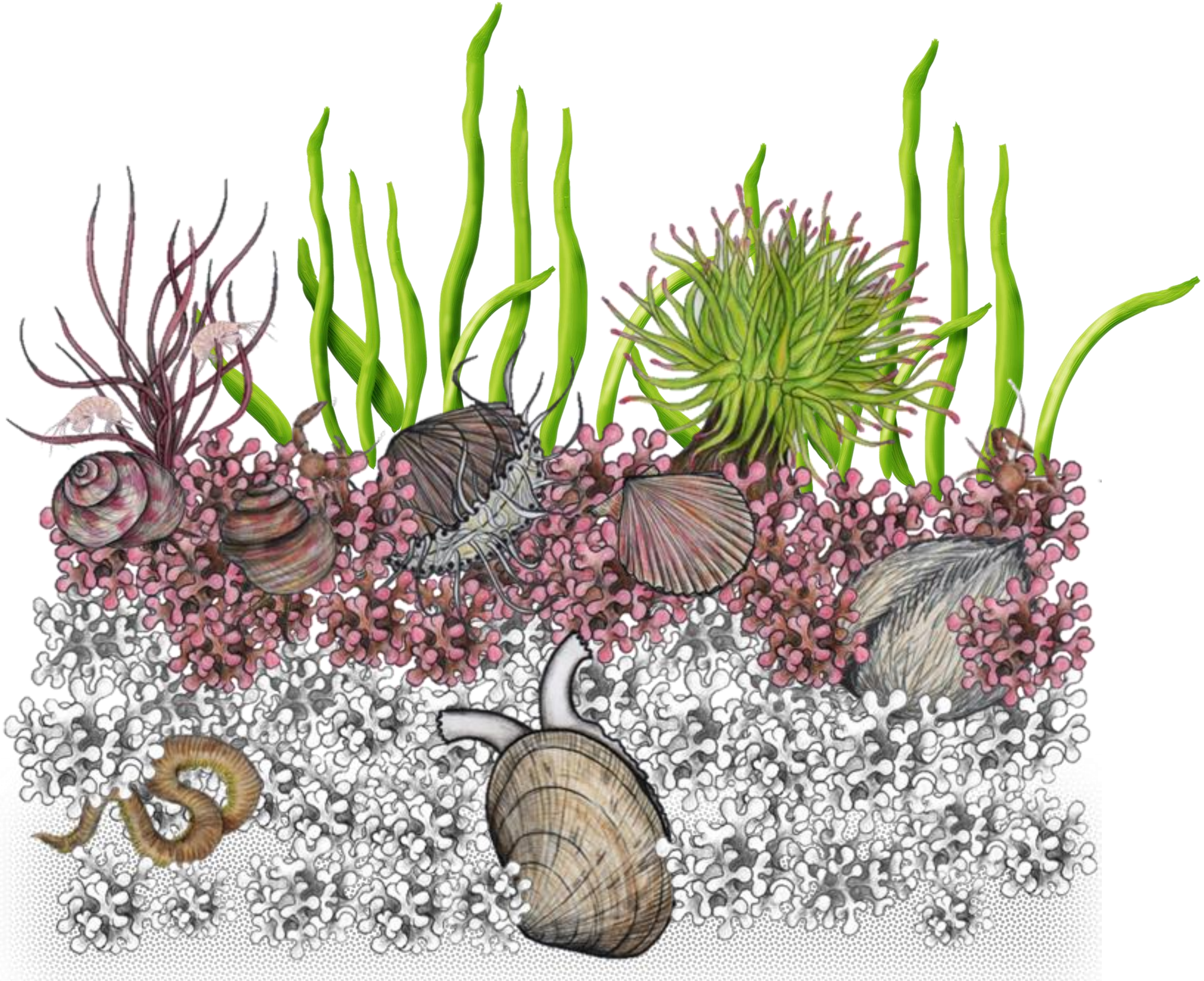
Worldwide distribution



Van der Heijden and Kamenos, 2017

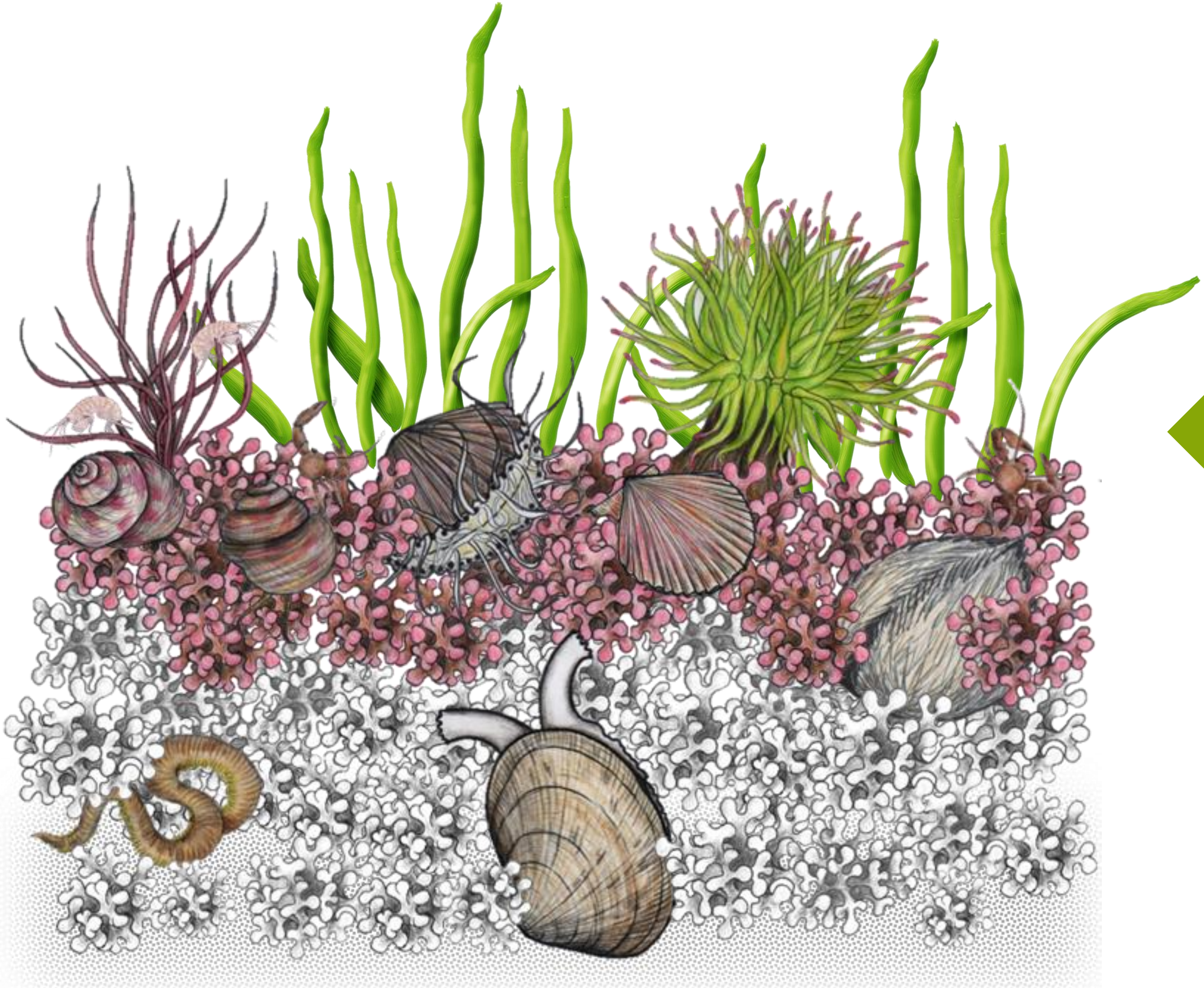
Three-dimensional system: 1000s years old

Graphic: Riosmena-Rodriguez et al. 2017



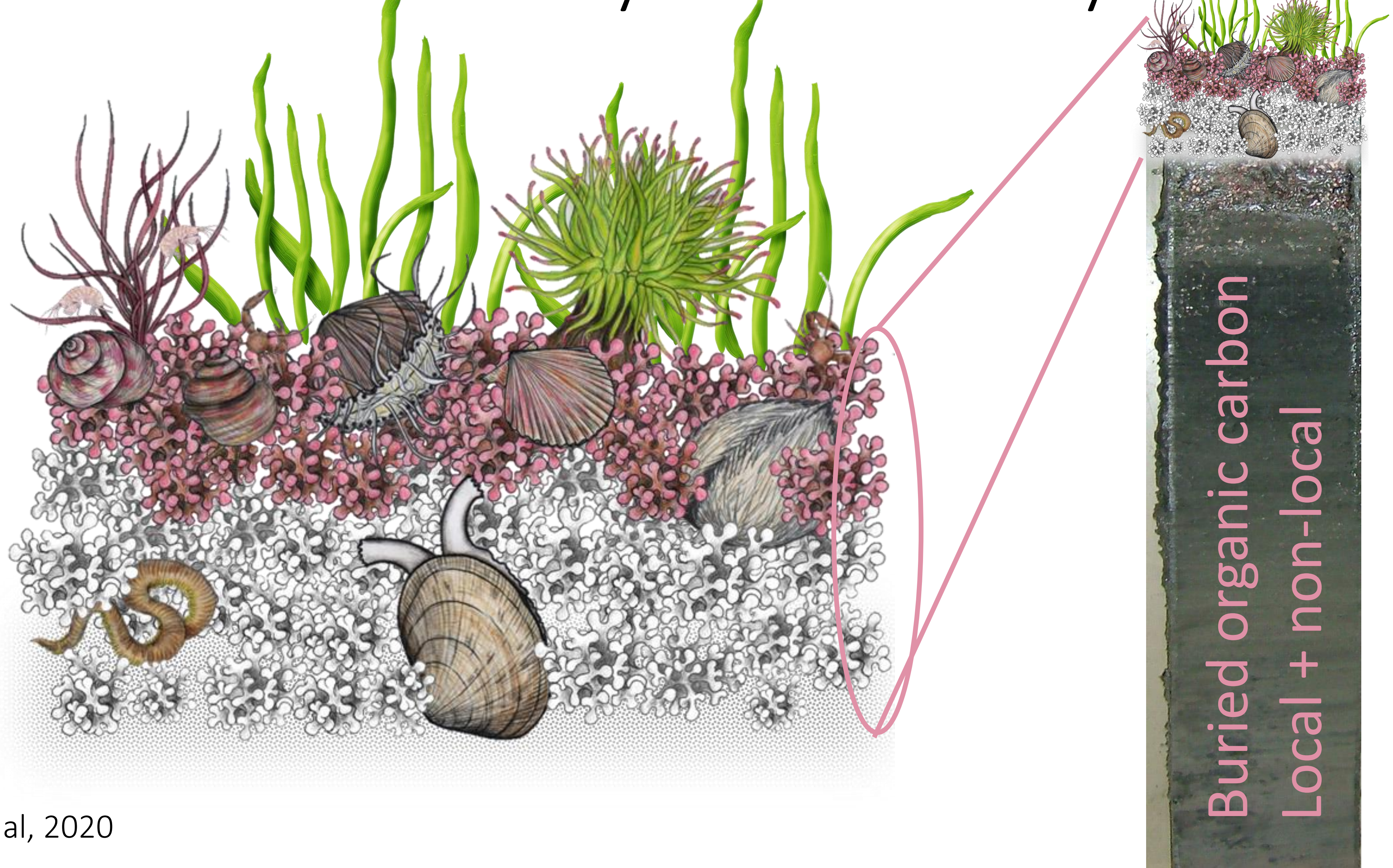
McCoy and Kamenos, 2015
Riosmena-Rodriguez et al, 2017
Mao et al, 2020

Three-dimensional system: 1000s years old



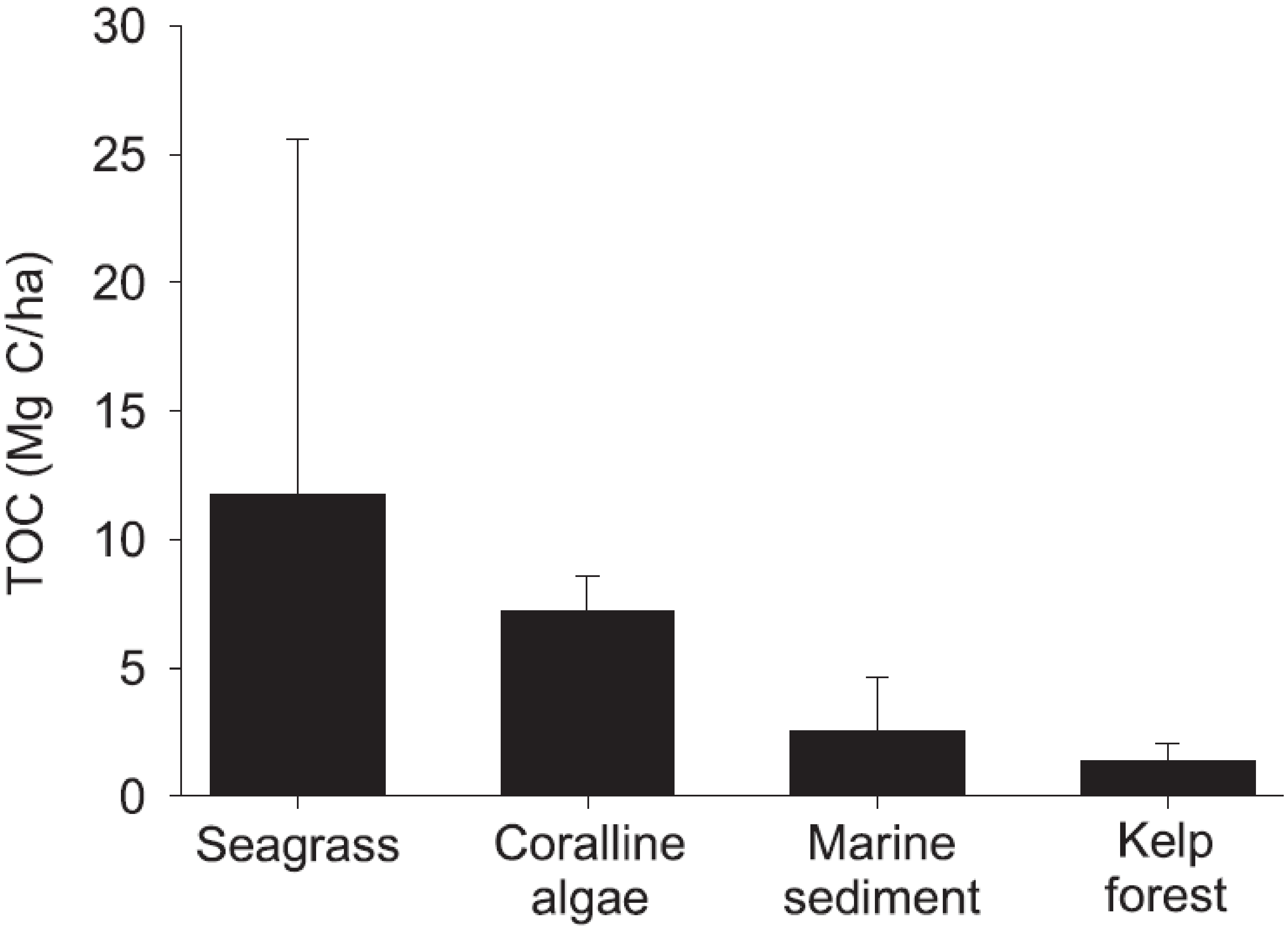
McCoy and Kamenos, 2015
Riosmena-Rodriguez et al, 2017
Mao et al, 2020

Three-dimensional system: 1000s years old



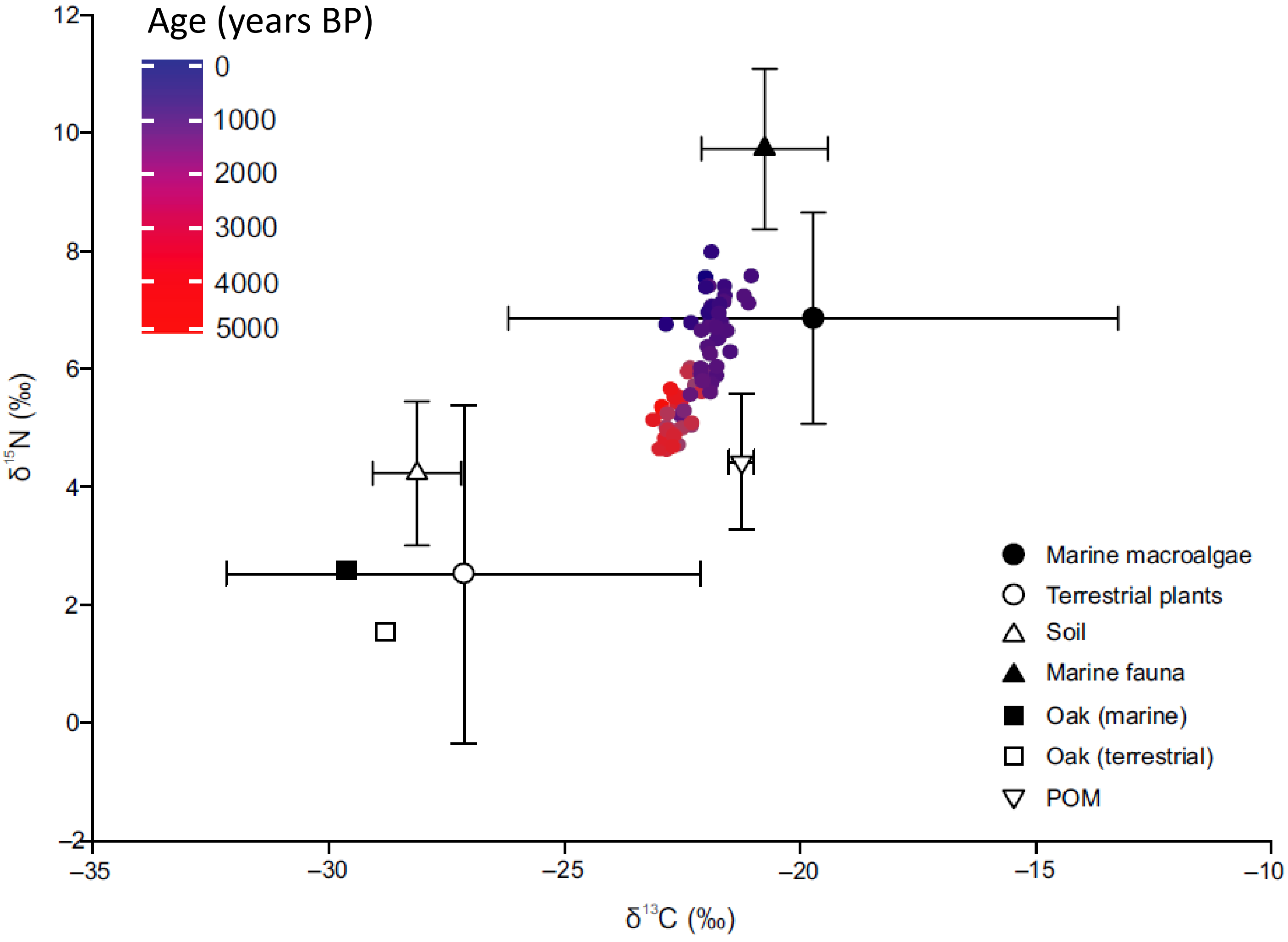
Mao et al, 2020

Large organic carbon stock



Mao et al, 2020

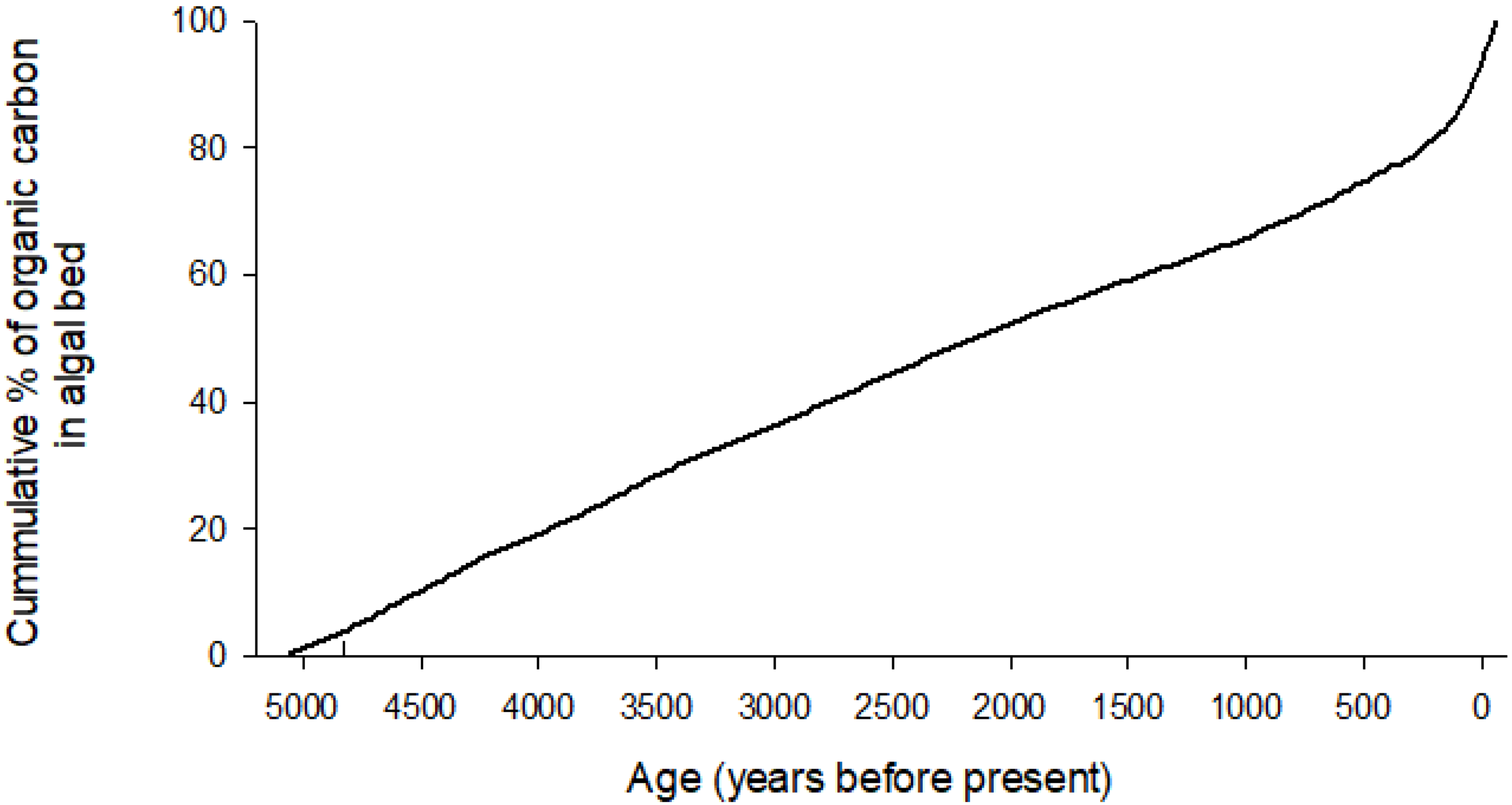
Opportunities: carbon “additionality”



Mao et al, 2020

Organic carbon source: marine fauna [10-40%], macroalgae [25-40%], terrestrial plants [~25%] and terrestrial soil [10-20%]

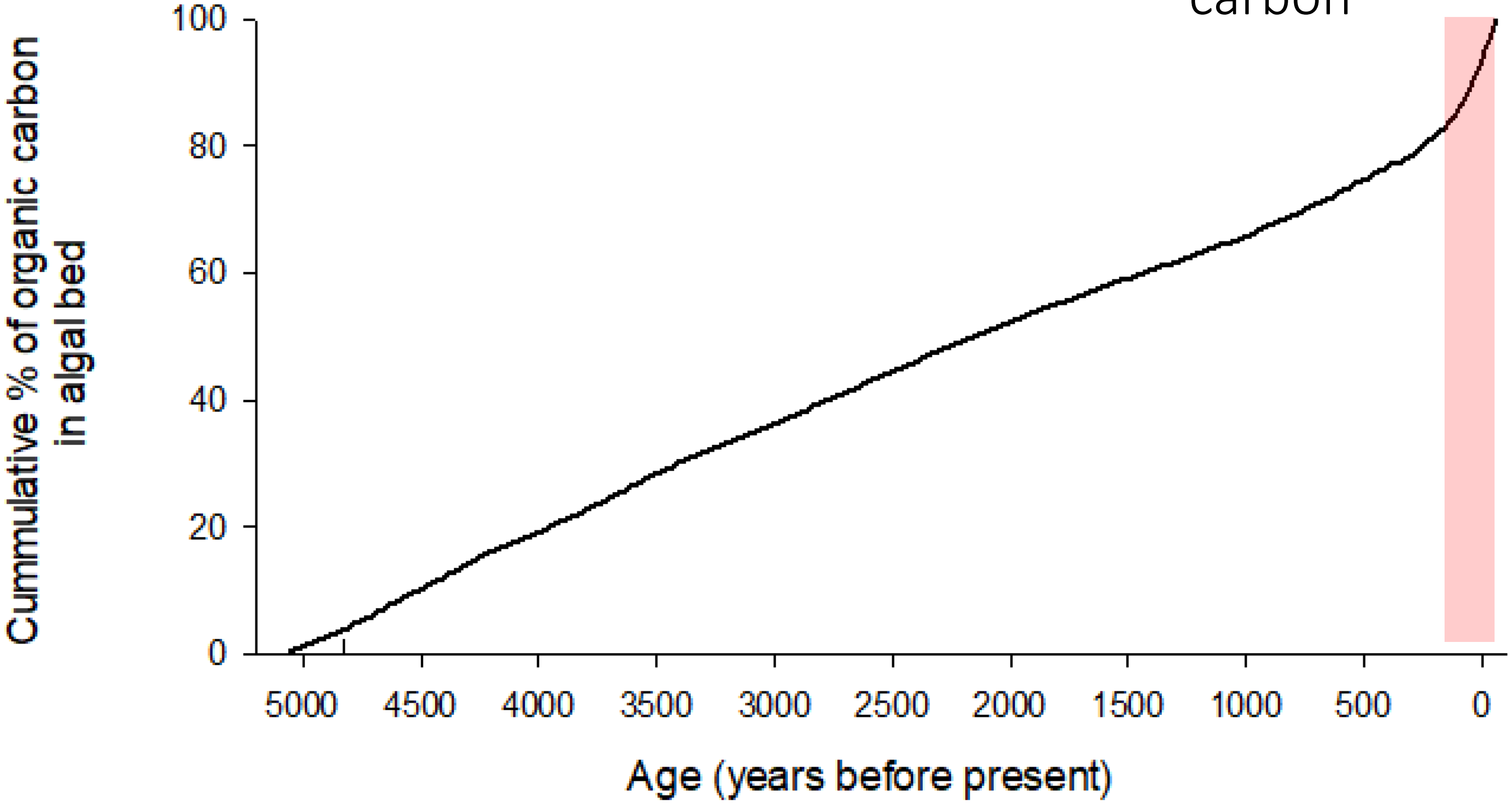
Challenges: disturbance and recovery



James et al, in prep
Mao et al, 2020

Challenges: disturbance and recovery

Just 10-20 cm disturbance remobilises 150y of carbon

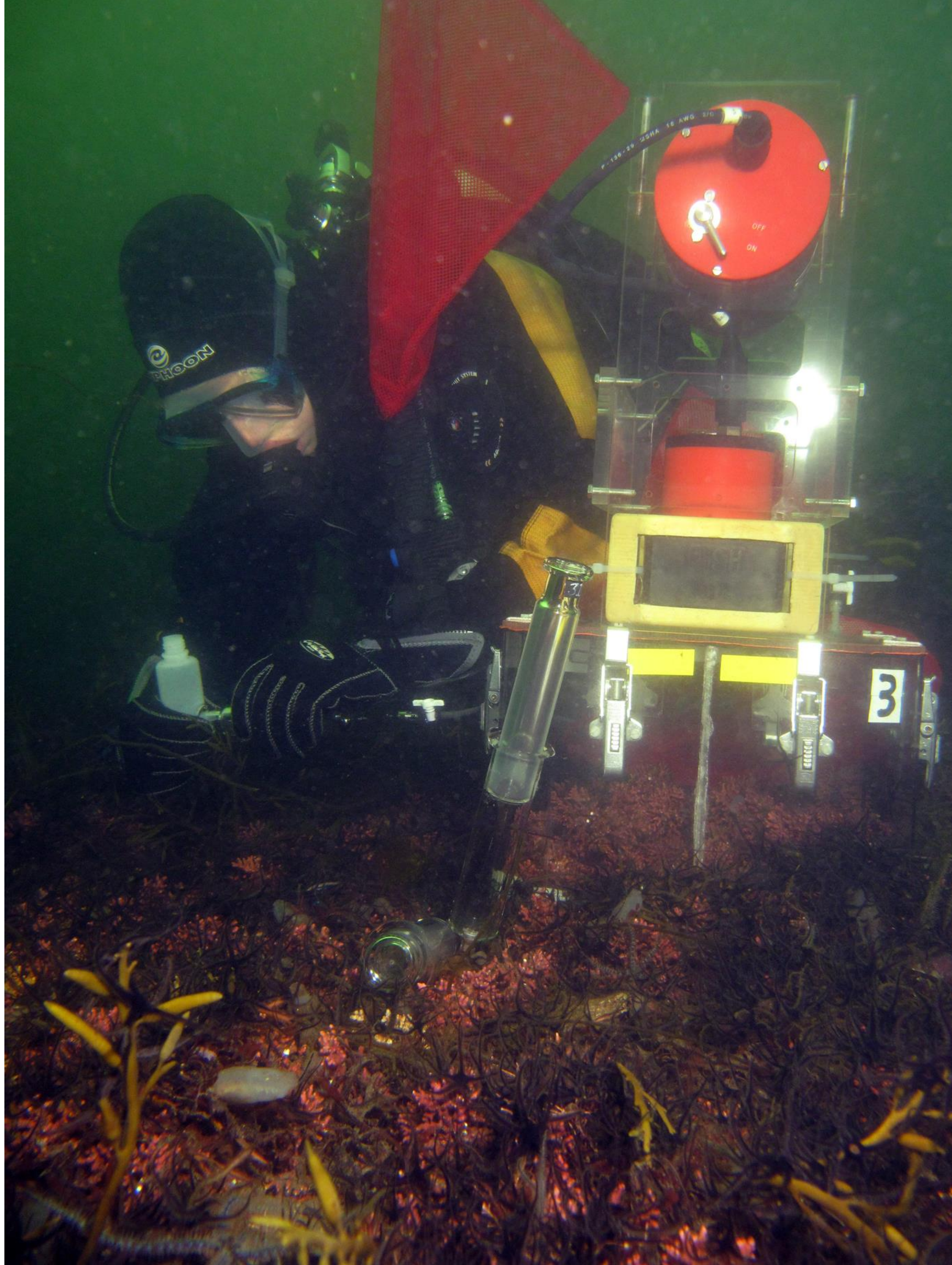


James et al, in prep
Mao et al, 2020


Future focus 1

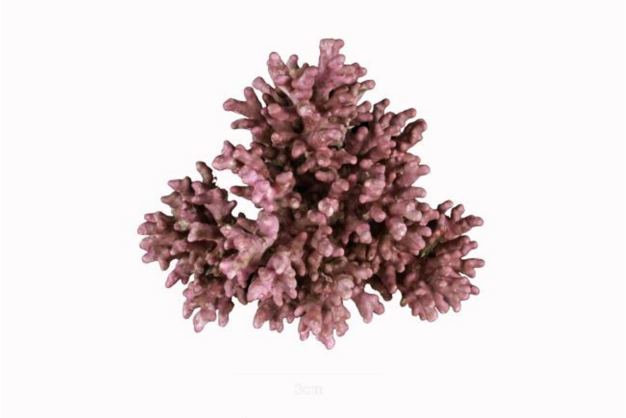
- Evaluate carbon removal at the ecosystem level
- Benthic algae rarely occur in isolation

Burdett et al,2018 James et al, In prep

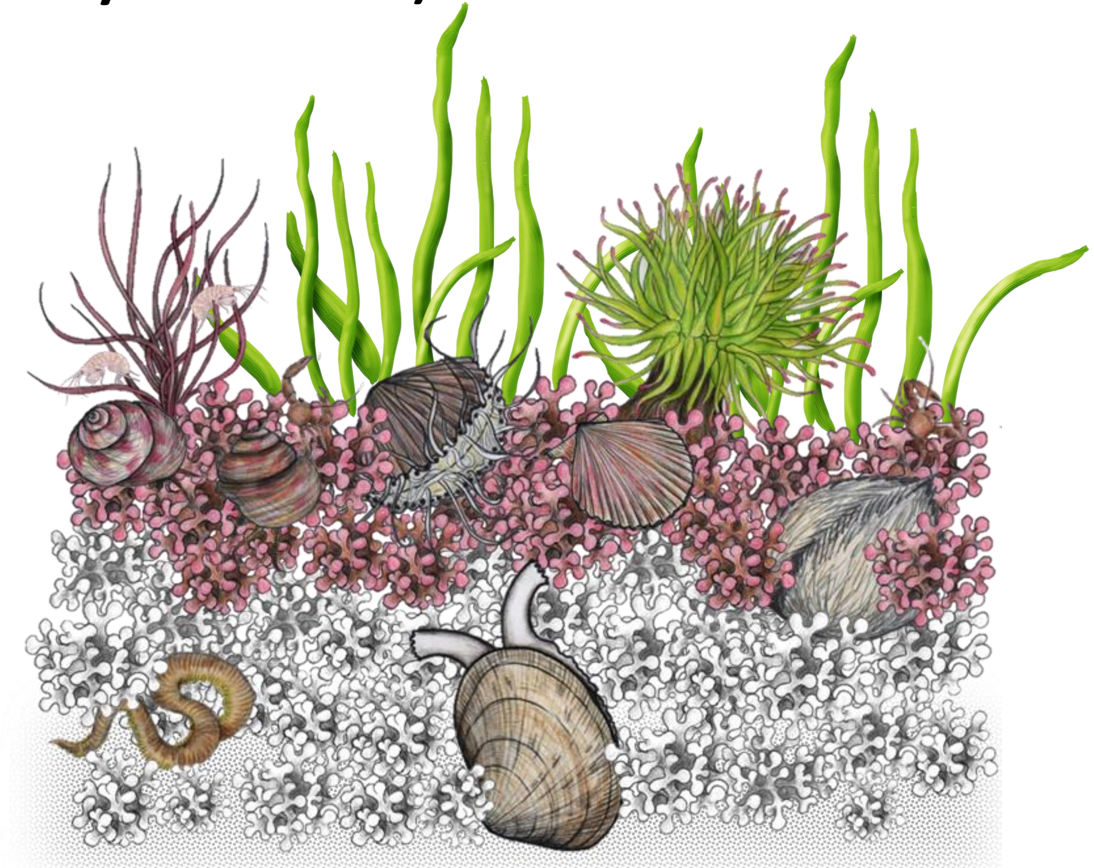


Future focus 2

- Calculate the balance of carbon release and burial (e.g. calcification vs photosynthesis) at “real world” scales



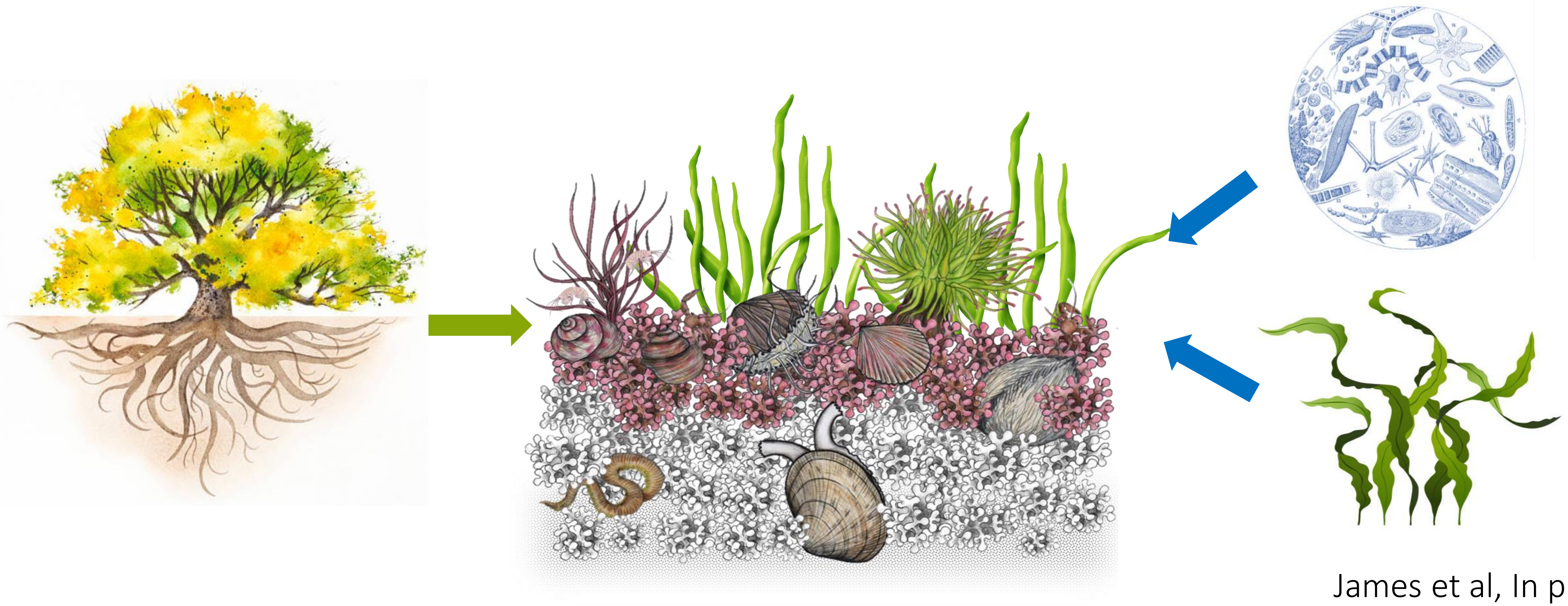
Vs



Mao et al, In prep, James et al, In prep

Future focus 3

- Integrate management of the carbon store <u>and</u> the **carbon supply chain**



James et al, In prep

Achieving carbon dioxide removal

- Move beyond individuals – need to consider ecosystem level responses
- Quantify the balance between carbon burial and release
- Strive for integrated management of carbon stores and their carbon supply chain

Acknowledgments

- Marine Global Change Group
- Nature Scot
- Natural Environmental Research Council
- Scottish Blue Carbon Forum
- Peter Macreadie
- Heidi Burdett
- John Baxter
- Ian Davies

NatureScot

UKRI

SCOTTISH BLUE CARBON FORUM
Understanding Scotland's coastal and marine carbon stores

References

Burdett, H.L., Perna, G., McKay, L., Broomhead, G., Kamenos, N.A. 2018. Community-level sensitivity of a calcifying ecosystem to acute in situ CO2 enrichment. Mar. Ecol. Prog. Ser. 587:73-80 doi: https://doi.org/10.3354/meps12421

Mao, J., Burdett, H. L., McGill, R. A. R., Newton, J., Gulliver, P., & Kamenos, N. A. 2020. Carbon burial over the last four millennia is regulated by both climatic and land use change. Global Change Biology. doi:10.1111/gcb.15021

McCoy, S. & Kamenos, N.A. 2015. Coralline algae in a changing world: Integrating ecological, physiological and geochemical responses to global change (review article). J. Phycol. 51:6-24 doi: 10.1111/jpy.12262

Riosmena-Rodríguez, R. Nelson, W. Aguire, J.(Eds). Rhodolith/Maerl Beds: A Global Perspective Elsevier. 2016 (ISBN: 3319293133)

van der Heijden, L. H., & Kamenos, N. A. 2015. Calculating the global contribution of coralline algae to total carbon burial. Biogeosciences, 12:6429-6441. doi:10.5194/bg-12-6429-201

Ocean Animals & Carbon

Andrew J. Pershing
apershing@climatecentral.org
@sci_officer

CLIMATE CENTRAL

Biomes

N. Tonelli, https://en.wikipedia.org/wiki/Deciduous

- Land: defined by plants

CLIMATE CENTRAL

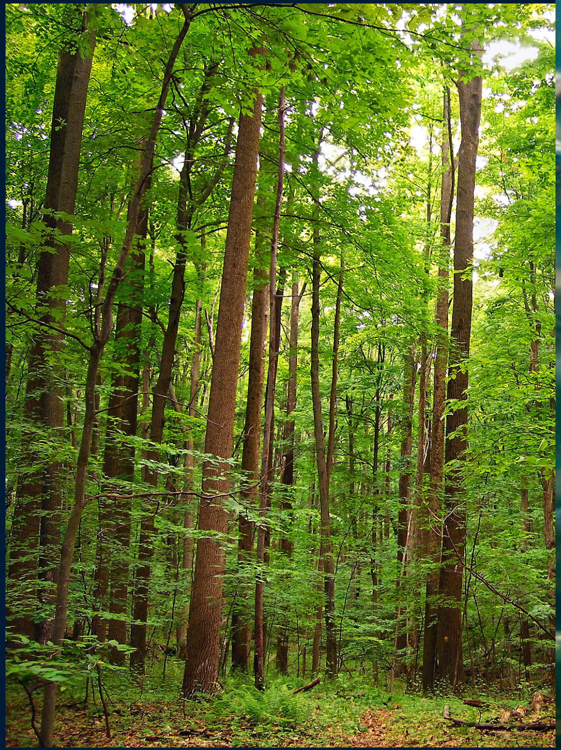
Biomes

N. Tonelli, https://en.wikipedia.org/wiki/Deciduous

W. Poon, https://en.wikipedia.org/wiki/Prairie

- Land: defined by plants

Biomes



N. Tonelli, https://en.wikipedia.org/wiki/Deciduous

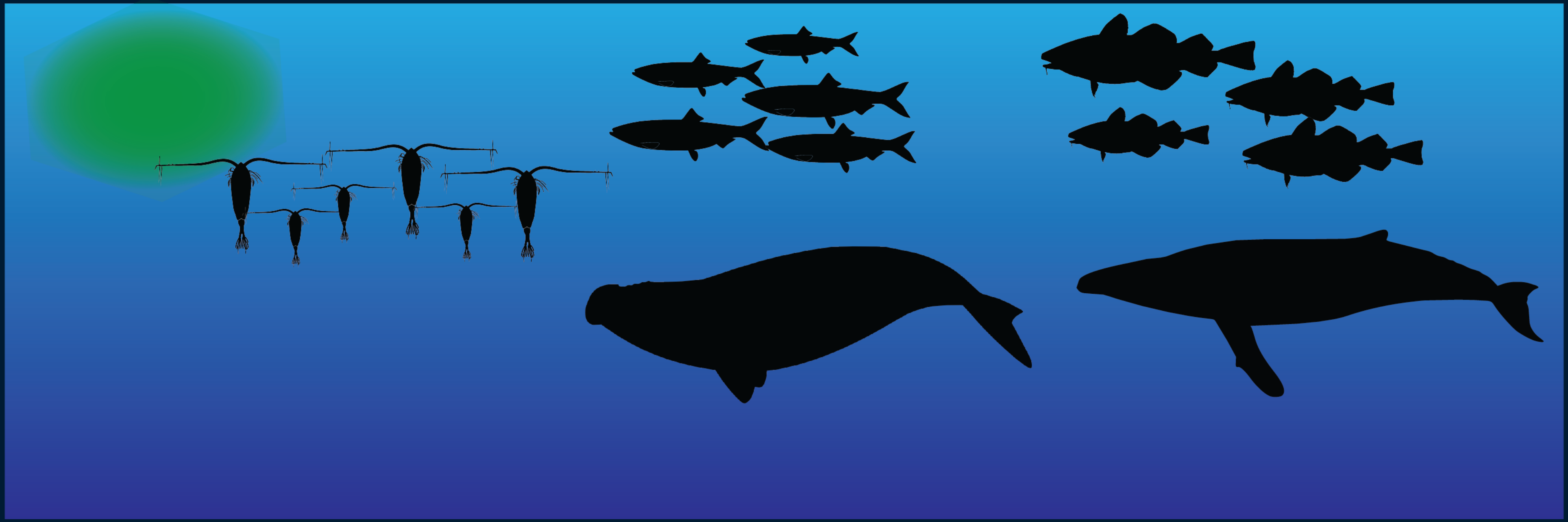
W. Poon, https://en.wikipedia.org/wiki/Prairie

J. Bøtter, https://www.washington.edu

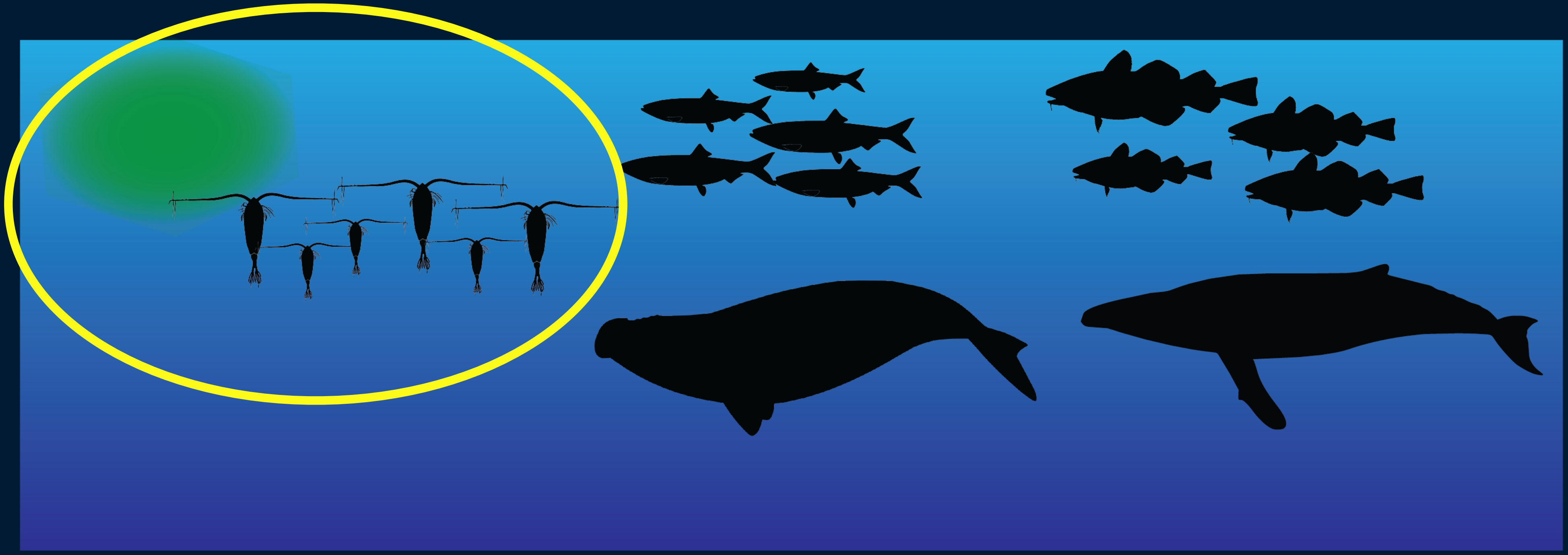
- Land: defined by plants
- Oceans: define by animals

CLIMATE CENTRAL

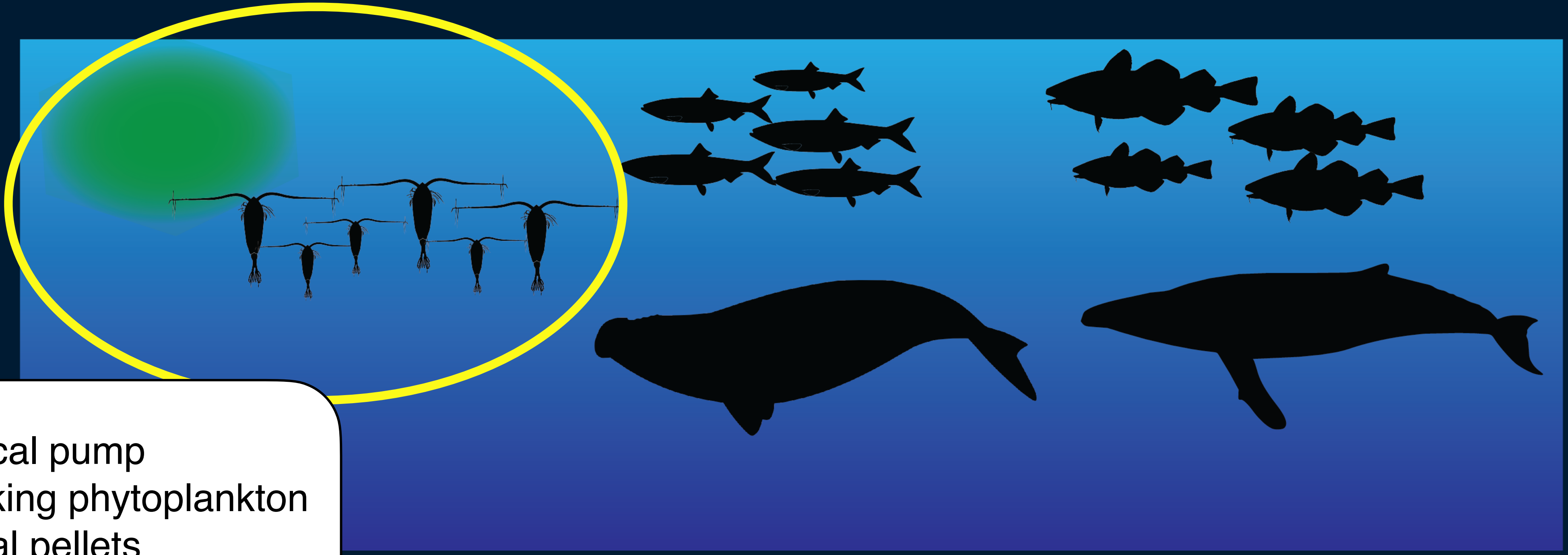
Ocean Ecosystems



Ocean Ecosystems



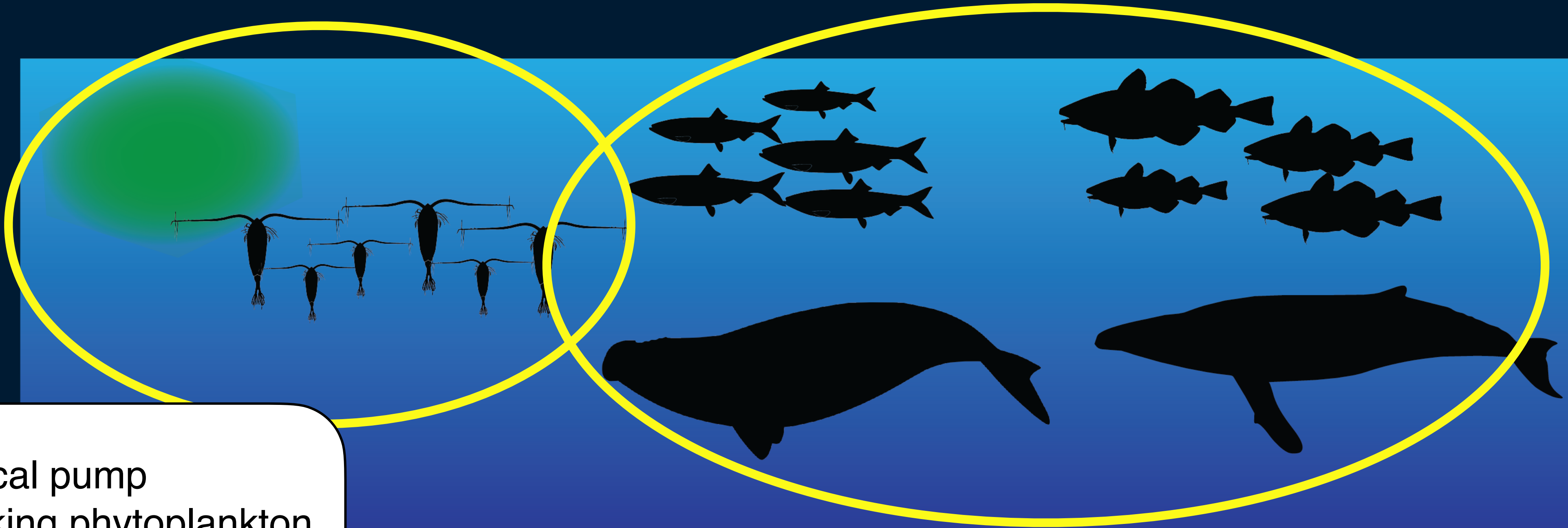
Ocean Ecosystems



- Biological pump
  - sinking phytoplankton
  - fecal pellets
  - diel vertical migration

CLIMATE CENTRAL

Ocean Ecosystems



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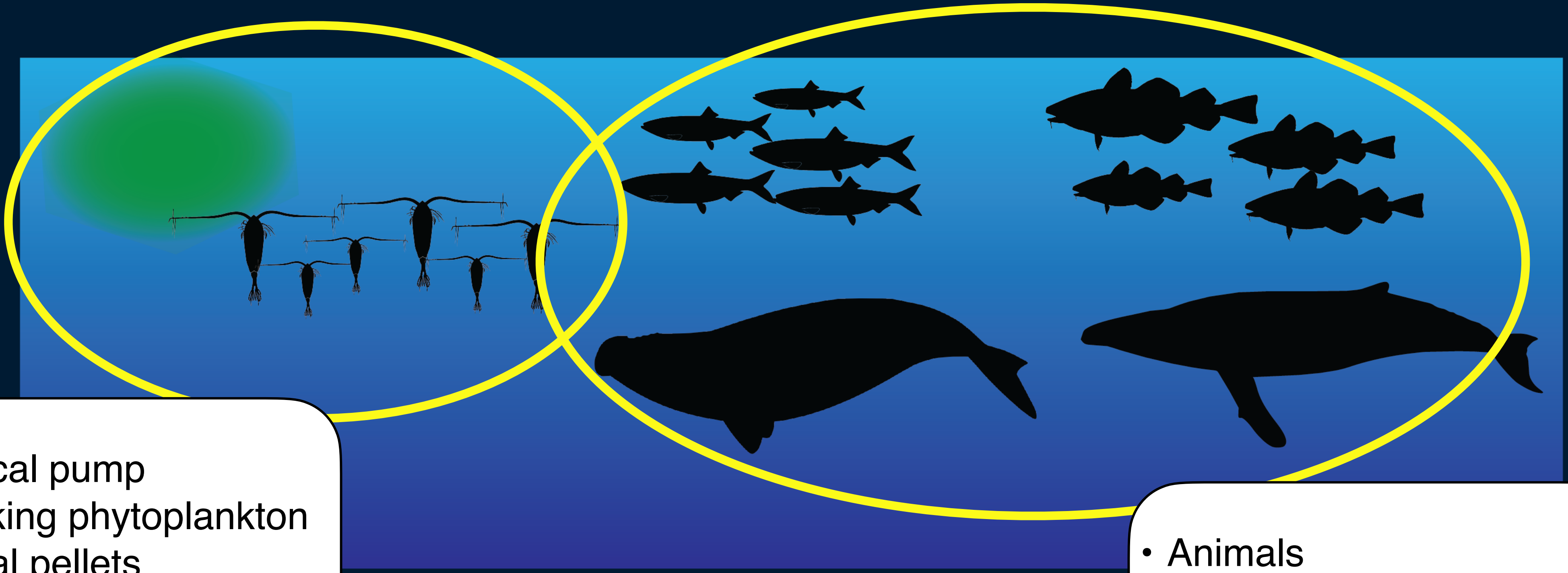
CLIMATE CENTRAL

Ocean Ecosystems

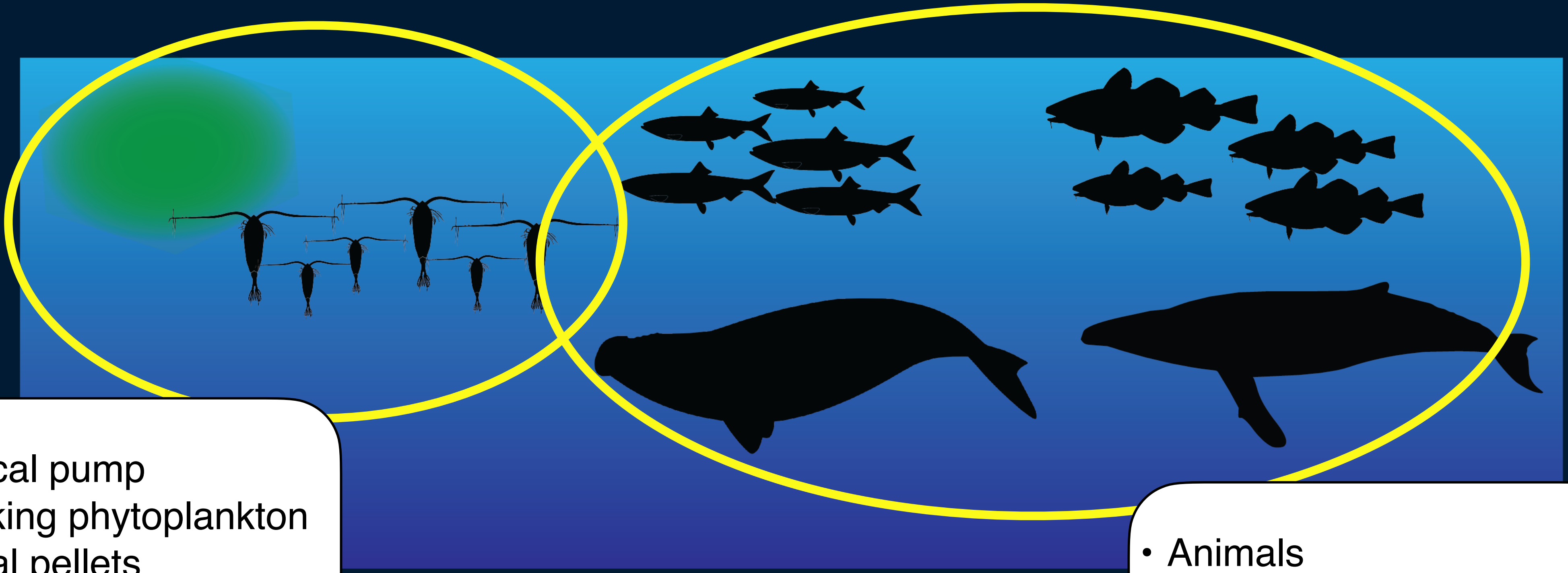


- Biological pump
    - sinking phytoplankton
    - fecal pellets
    - diel vertical migration

- Animals
    - store carbon
    - export through sinking
    - move nutrients around

CLIMATE CENTRAL

Ocean Ecosystems



- Biological pump
  - sinking phytoplankton
  - fecal pellets
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\+ Lots of carbon
\- Out of our control

- Animals
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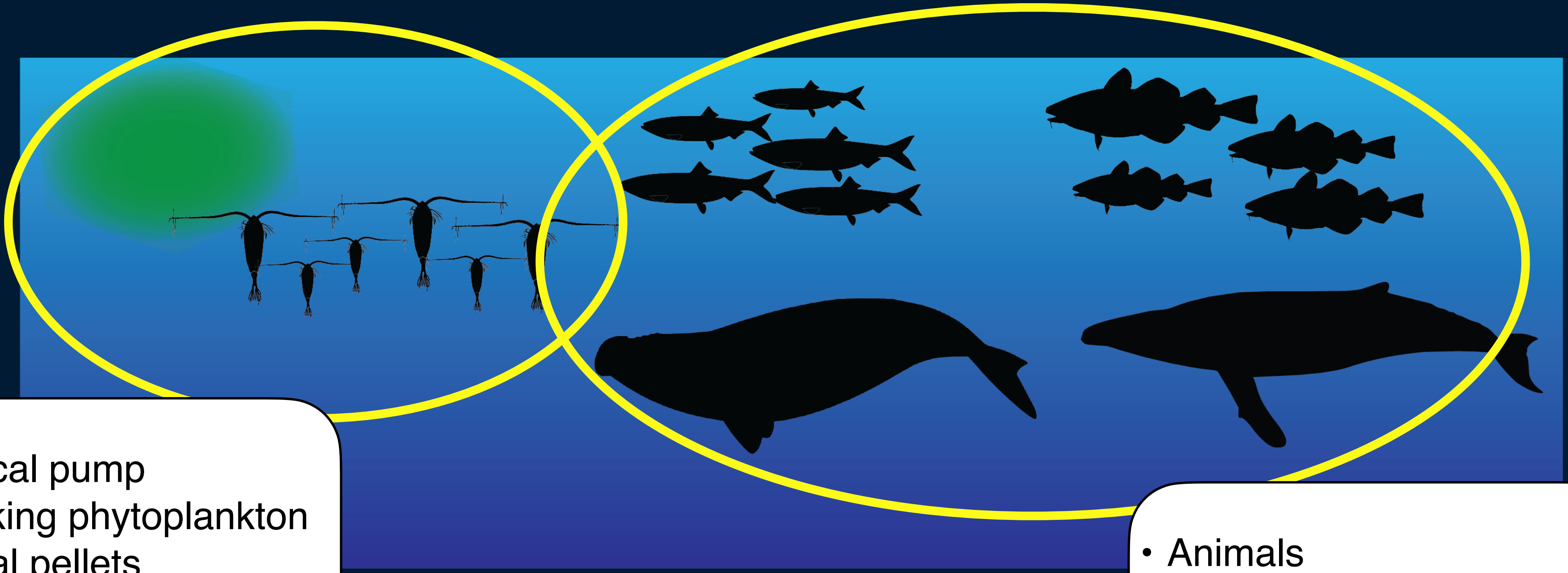
  - export through sinking
  - move nutrients around

Ocean Ecosystems



- Biological pump
    - sinking phytoplankton
    - fecal pellets
    - diel vertical migration

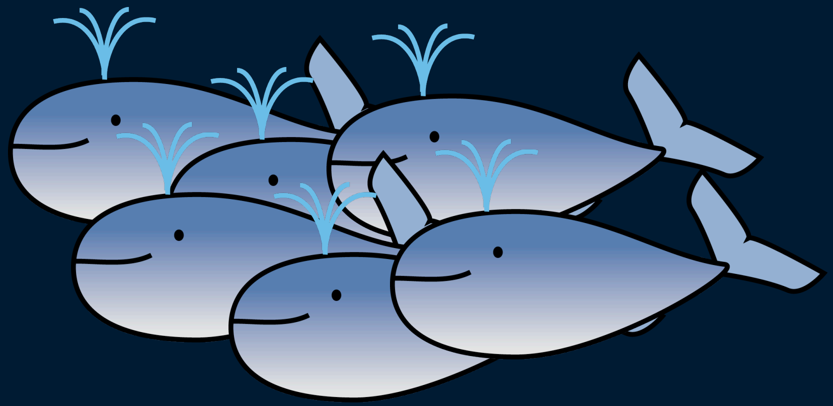
\+ Lots of carbon
\- Out of our control

- Animals
    - store carbon
    - export through sinking
    - move nutrients around

\- Less carbon
\+ Humans in the loop

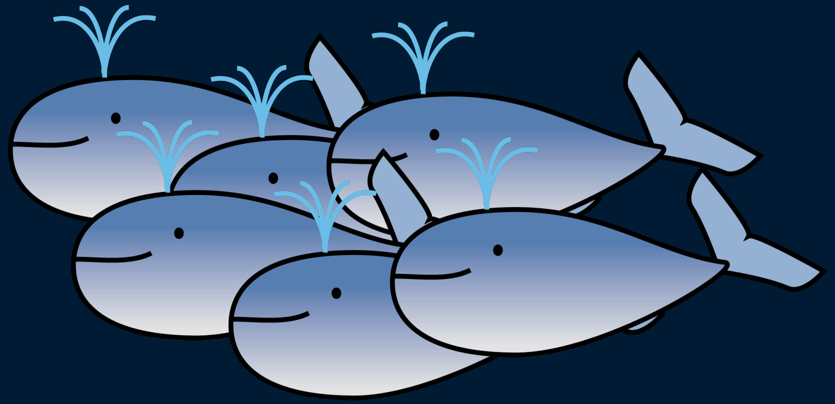
CLIMATE CENTRAL

Ex: Blue Whales



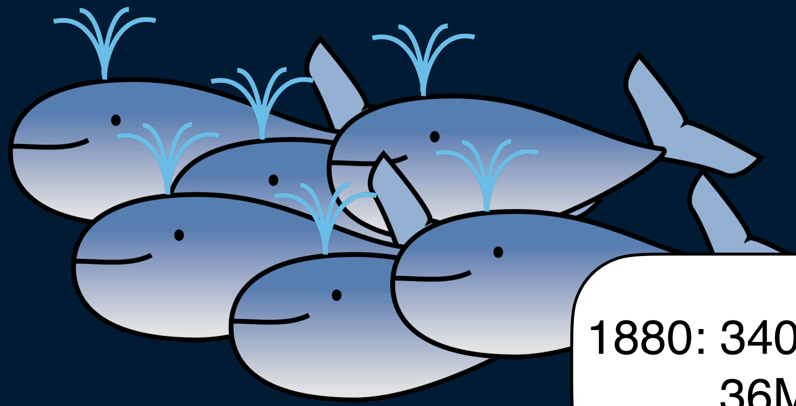
CLIMATE CENTRAL

Ex: Blue Whales

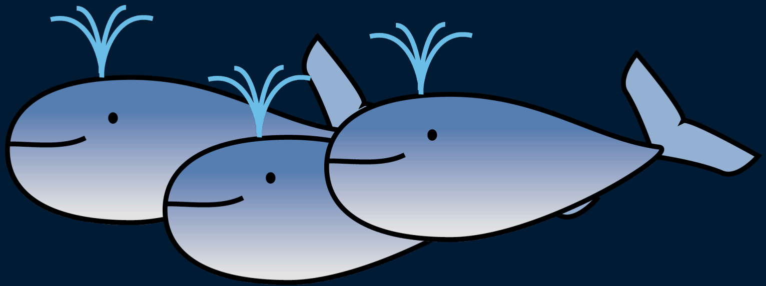


CLIMATE CENTRAL

Ex: Blue Whales



1880: 340,000 whales
36M tons



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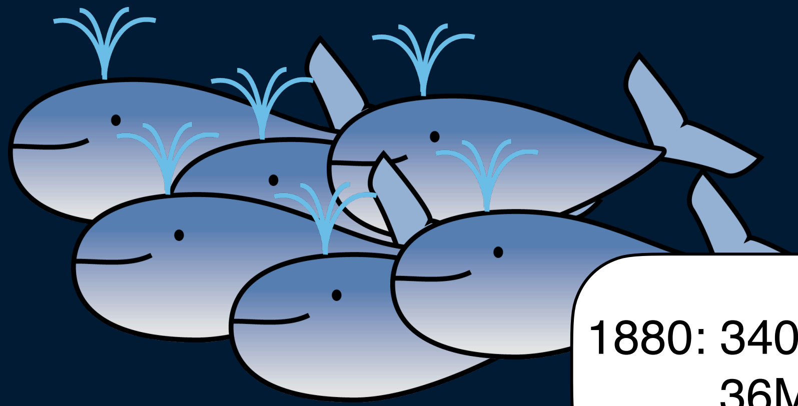

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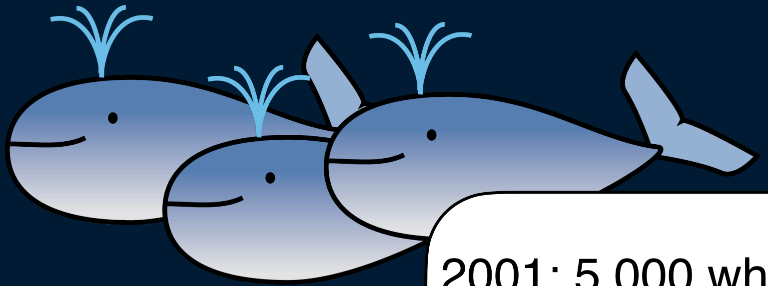
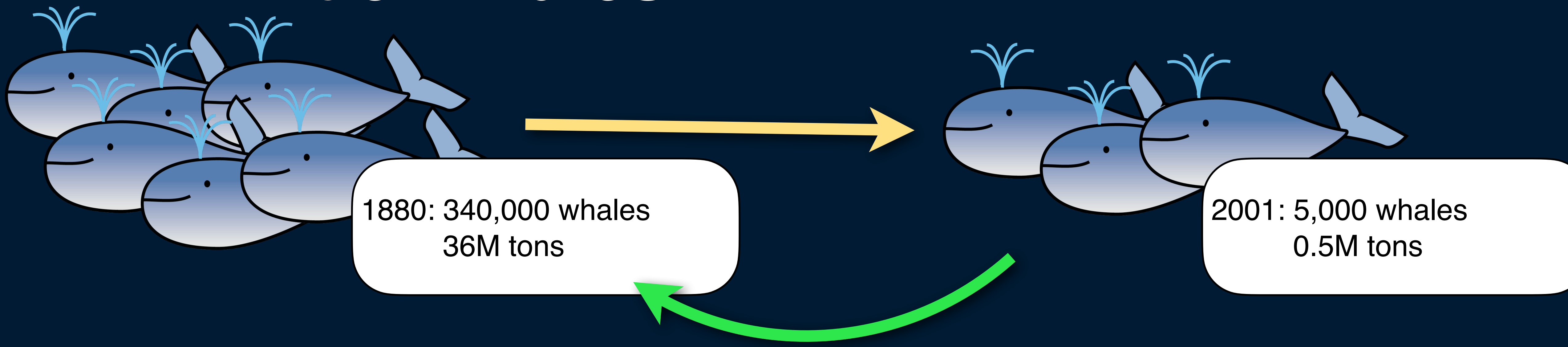


2001: 5,000 whales
0.5M tons

CLIMATE CENTRAL

Ex: Blue Whales



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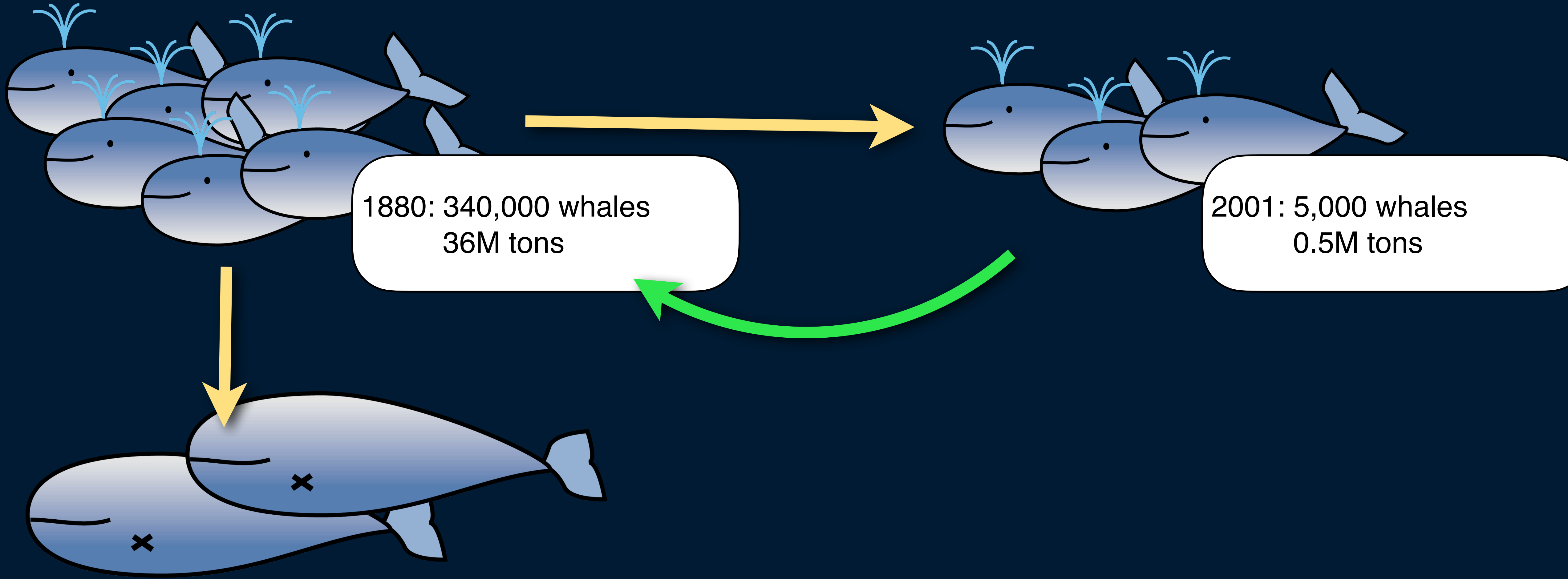

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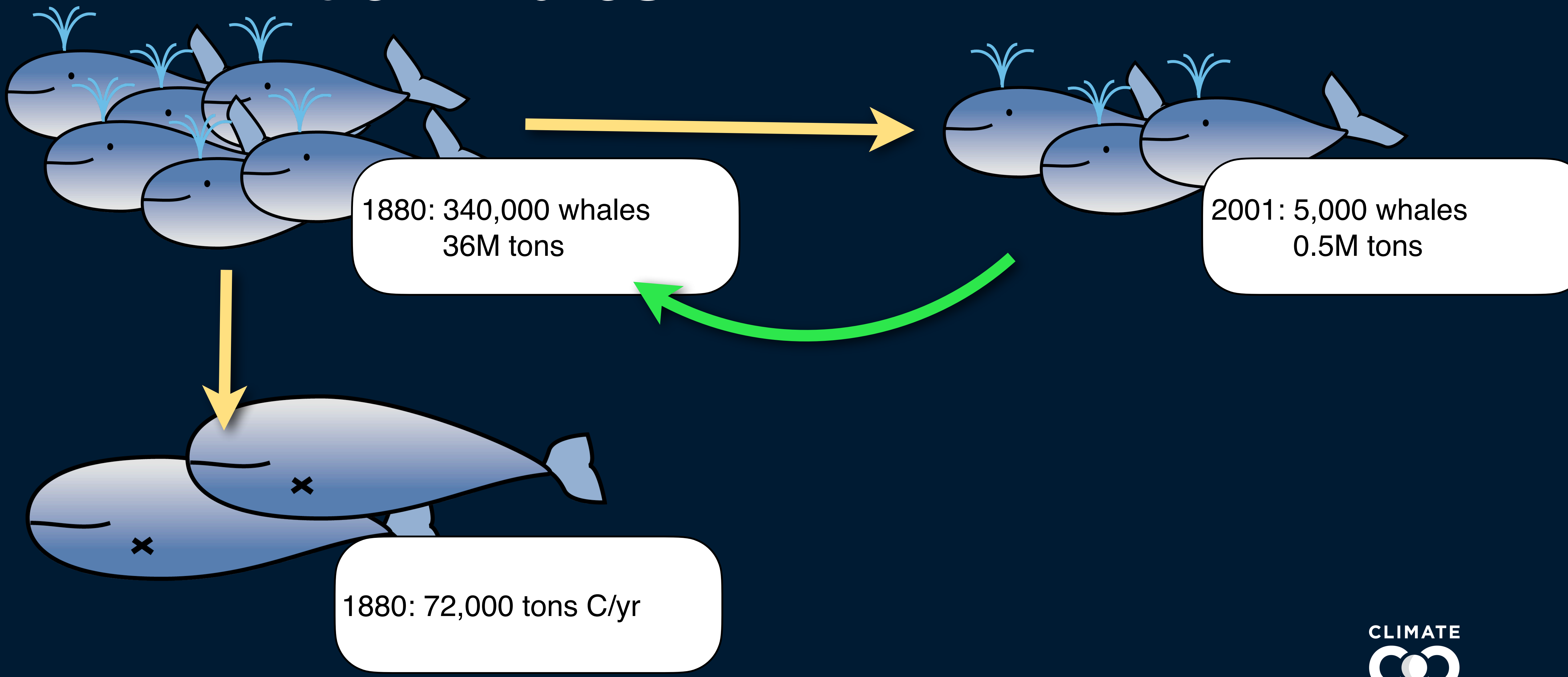

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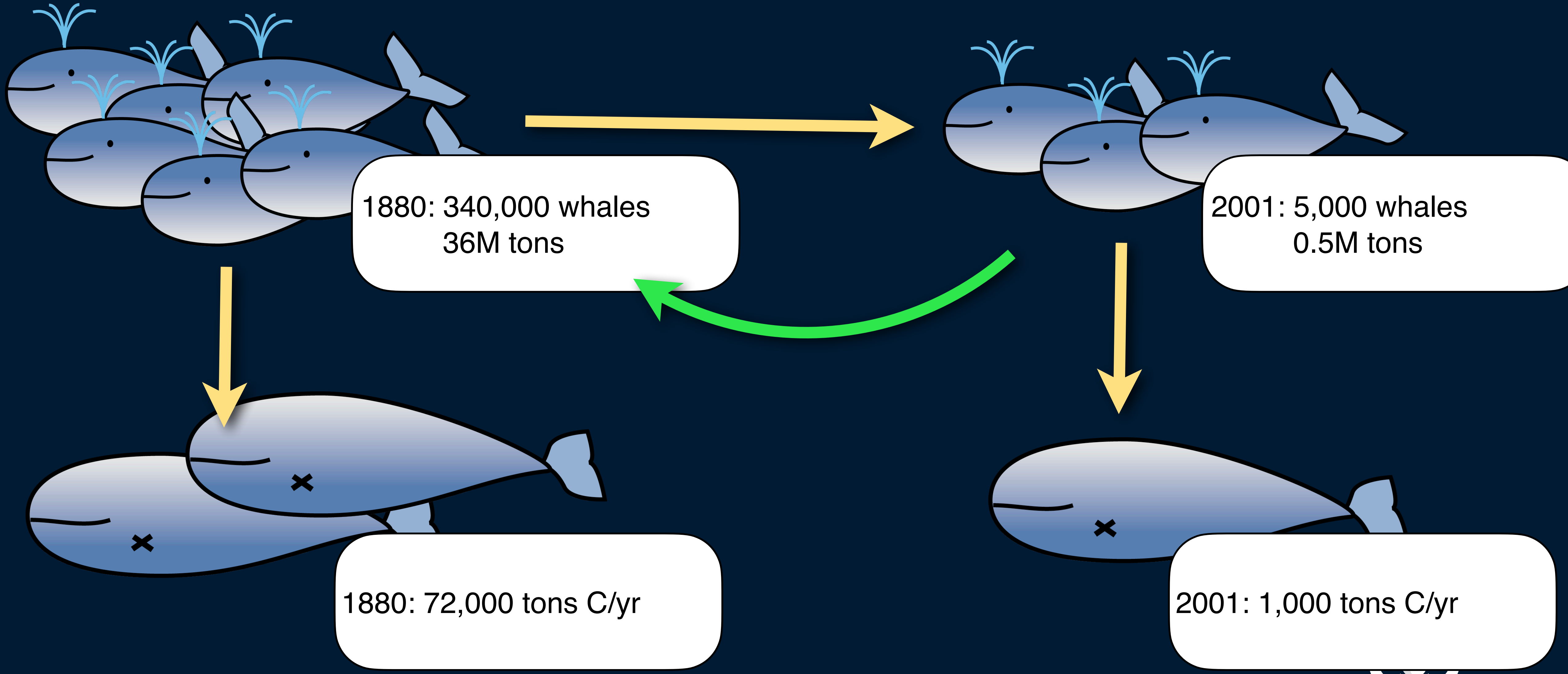
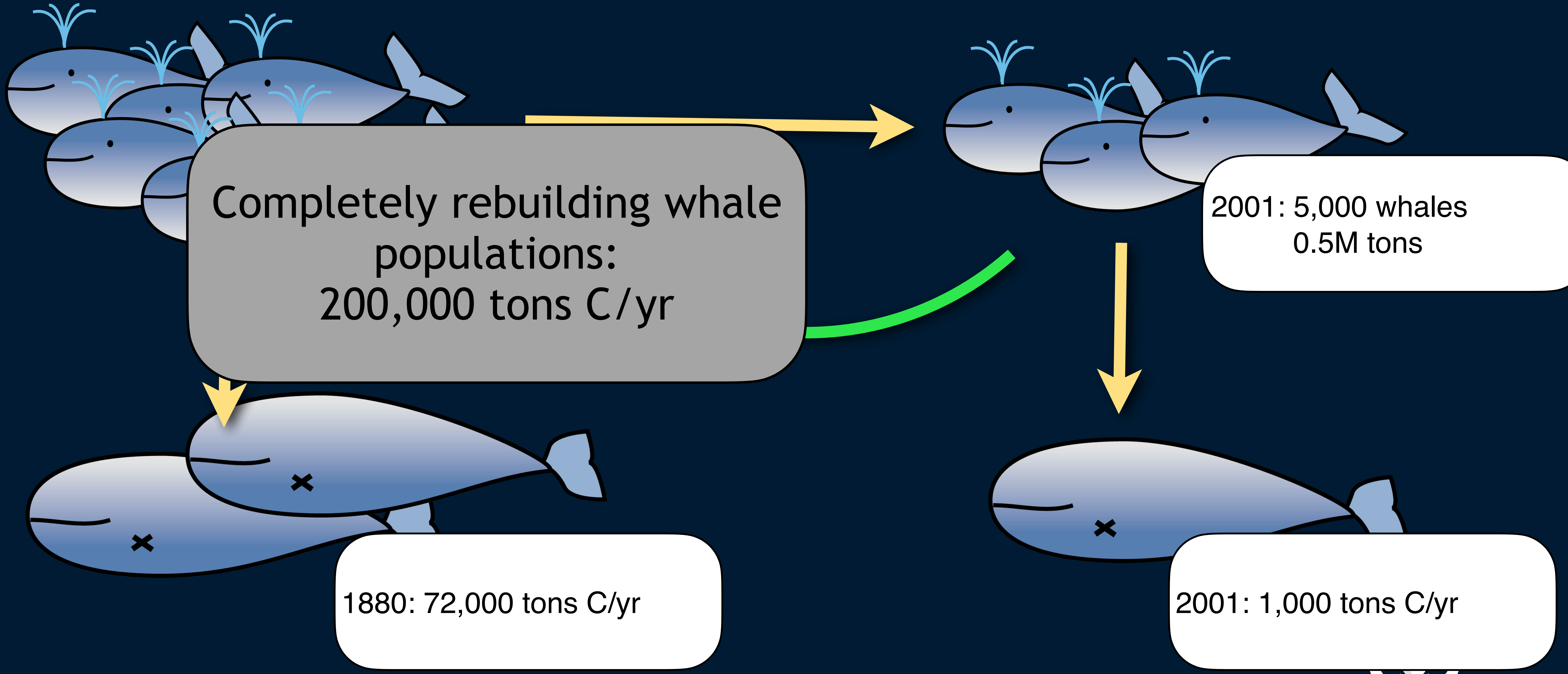
Ex: Blue Whales



Ex: Blue Whales



Ex: Blue Whales

Completely rebuilding whale populations:
200,000 tons C/yr

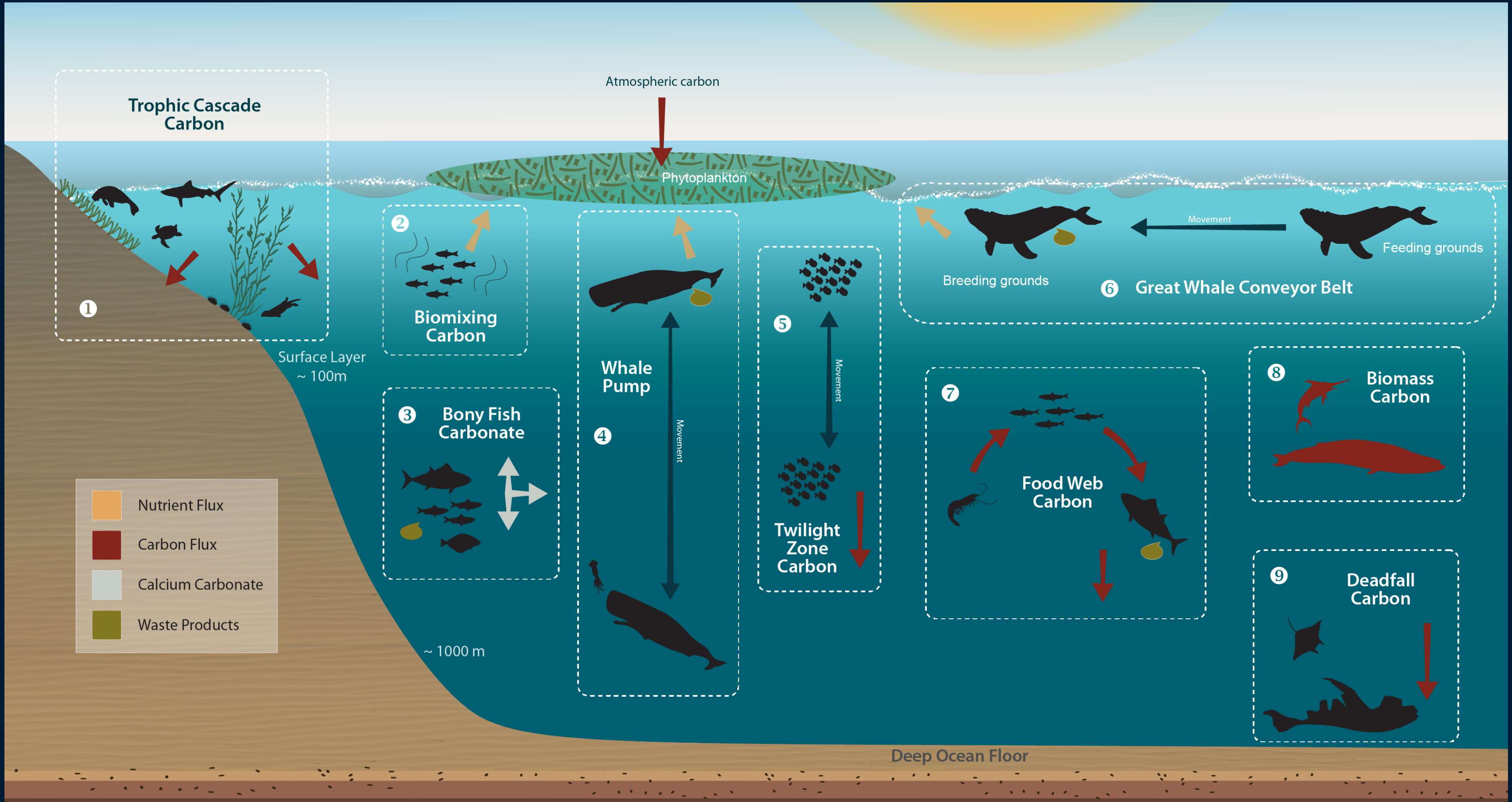
2001: 5,000 whales
0.5M tons

1880: 72,000 tons C/yr

2001: 1,000 tons C/yr

CENTRAL

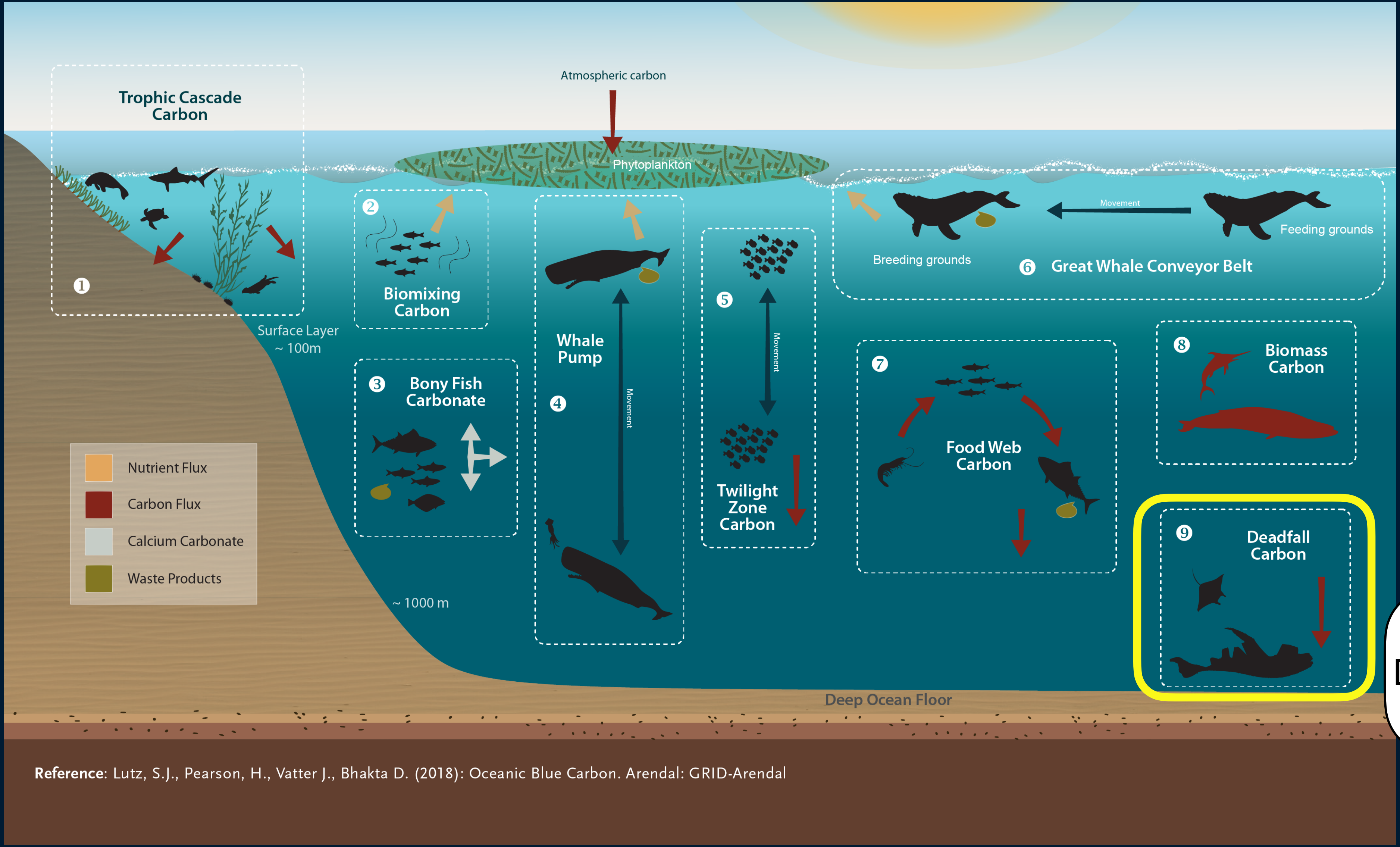
Ocean animals & the carbon cycle



Reference: Lutz, S.J., Pearson, H., Vatter J., Bhakta D. (2018): Oceanic Blue Carbon. Arendal: GRID-Arendal

CLIMATE CENTRAL

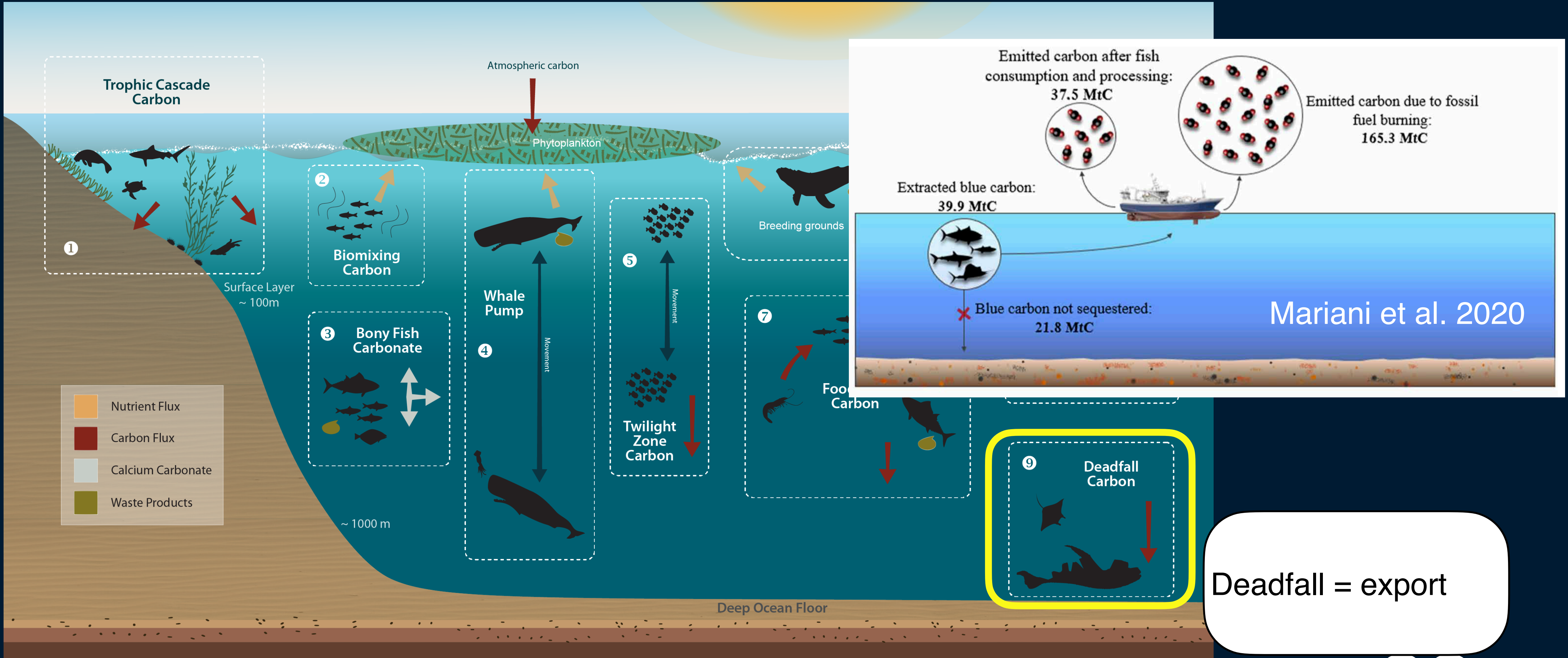
Ocean animals & the carbon cycle



Deadfall = export

CENTRAL

Ocean animals & the carbon cycle



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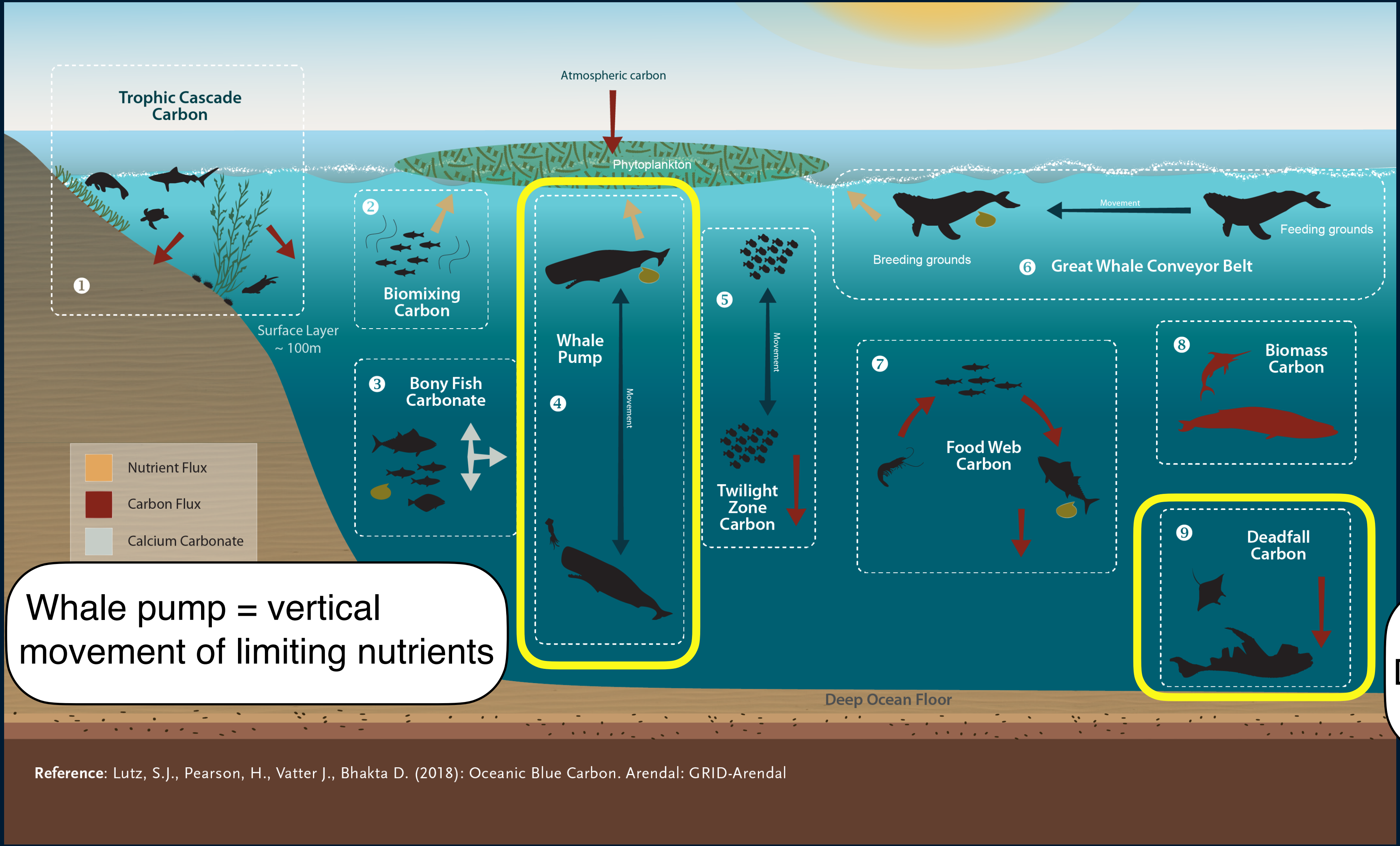
Ocean animals & the carbon cycle

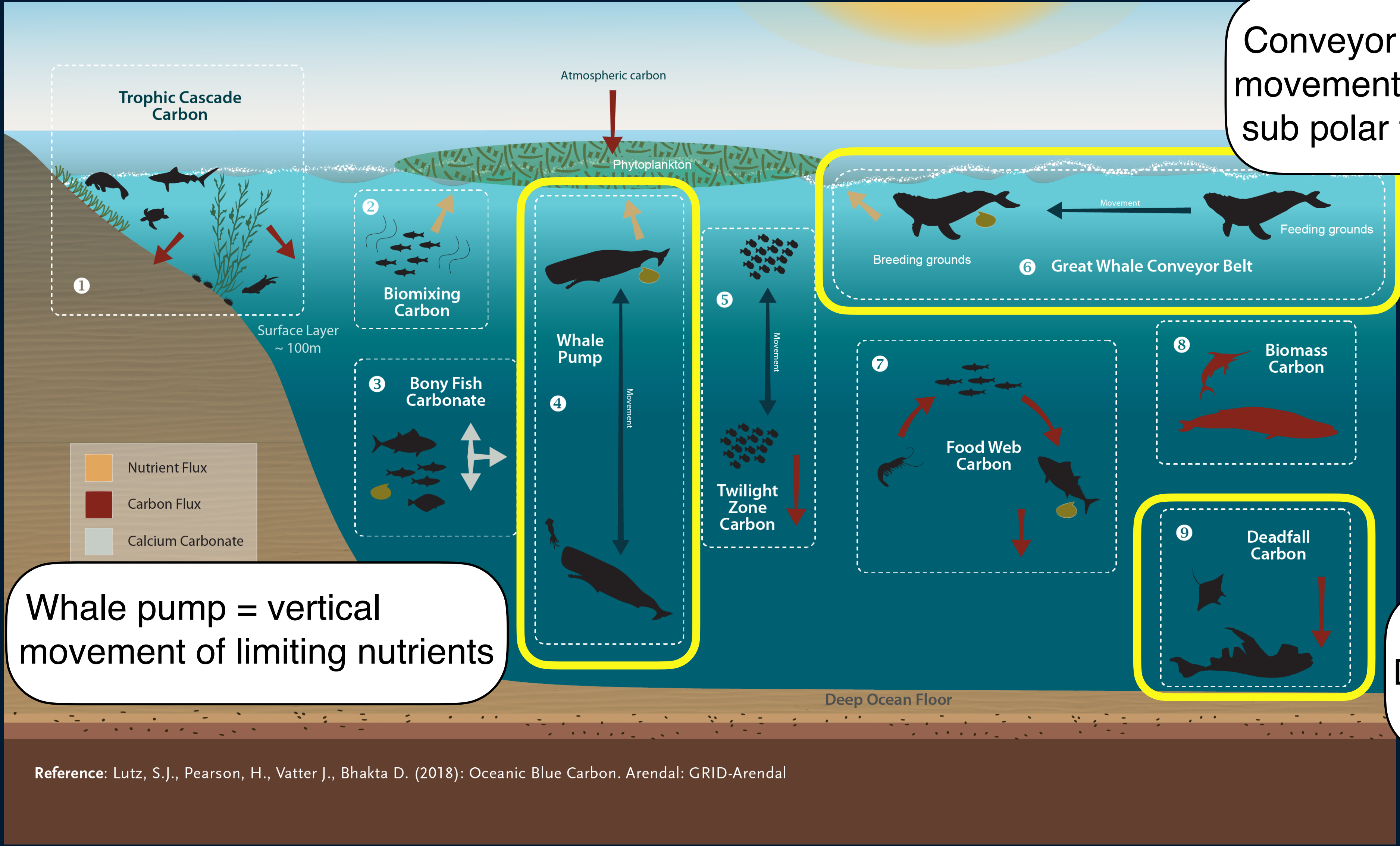


Whale pump = vertical movement of limiting nutrients

Deadfall = export

CENTRAL

Ocean animals & the carbon cycle



Conveyor belt = horizontal movement of limiting nutrients (i.e. sub polar to tropical)

Whale pump = vertical movement of limiting nutrients

Deadfall = export

Reference: Lutz, S.J., Pearson, H., Vatter J., Bhakta D. (2018): Oceanic Blue Carbon. Arendal: GRID-Arendal

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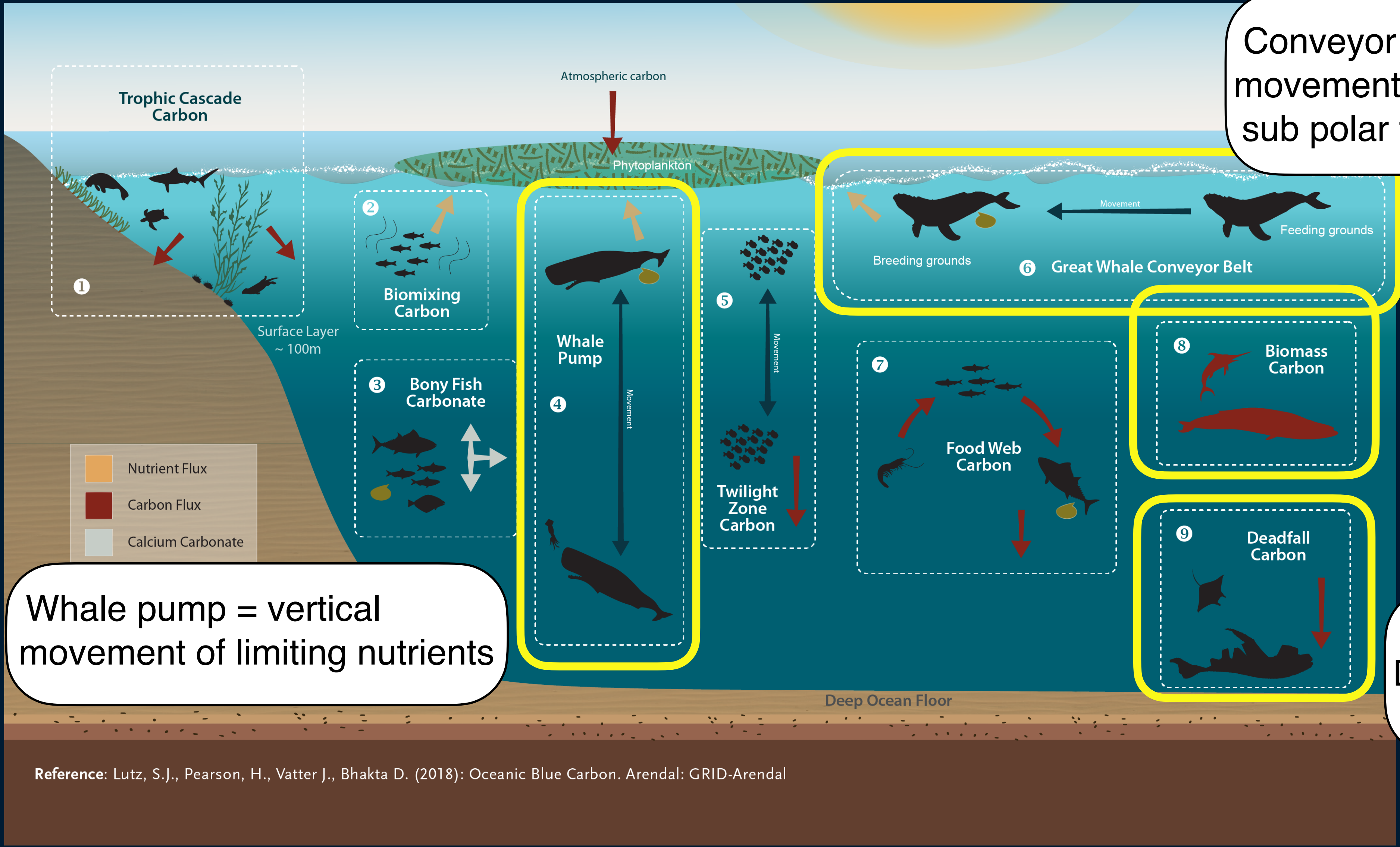
Ocean animals & the carbon cycle



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Conveyor belt = horizontal movement of limiting nutrients (i.e. sub polar to tropical)

Biomass: are whales redwoods?

Whale pump = vertical movement of limiting nutrients

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Biomass: Bigger is better

- Big animals do amazing things

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  - High metabolic efficiency

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Biomass: Bigger is better

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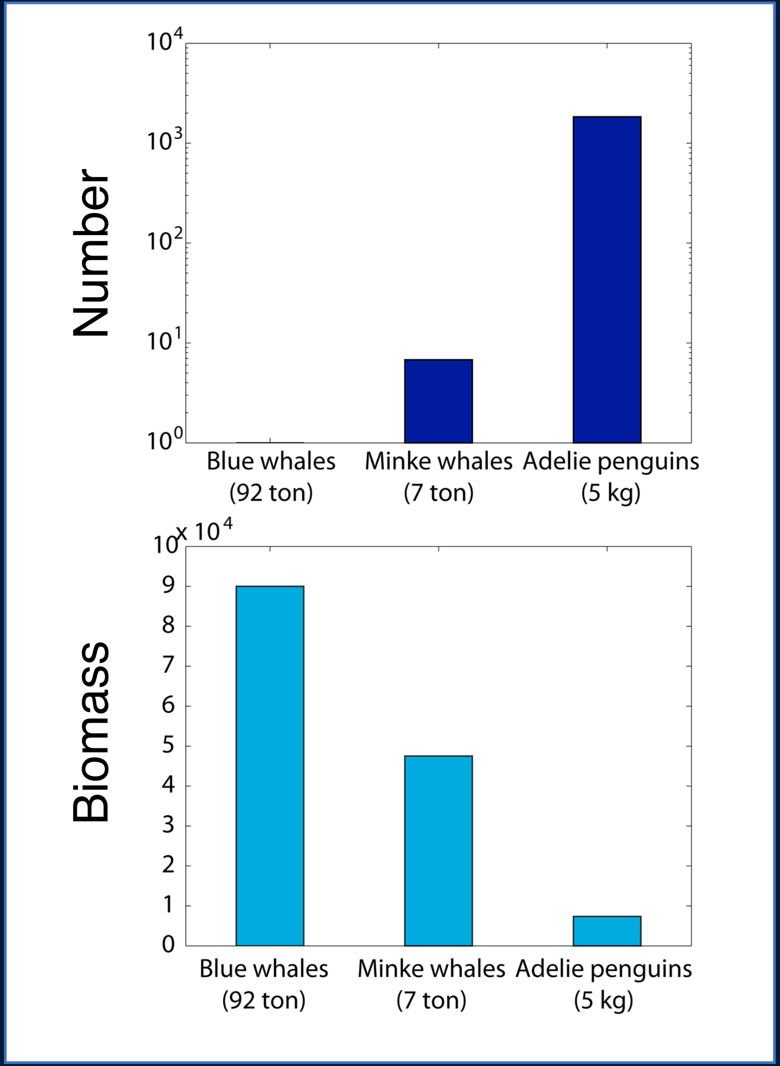
    - Same food (krill) that supports one 92 ton blue whale

One Blue Whale's Food



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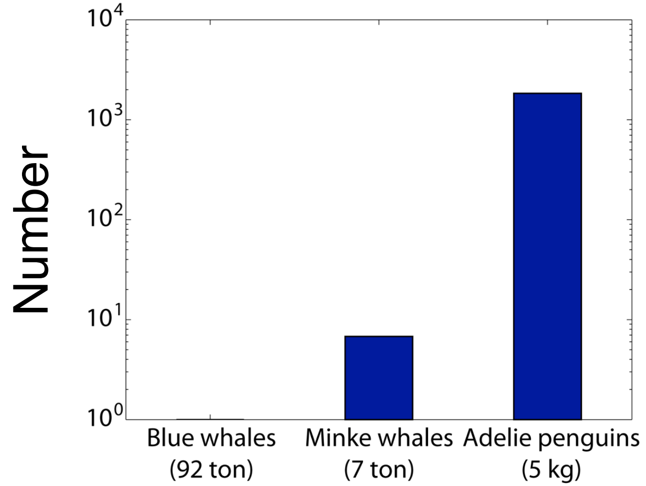

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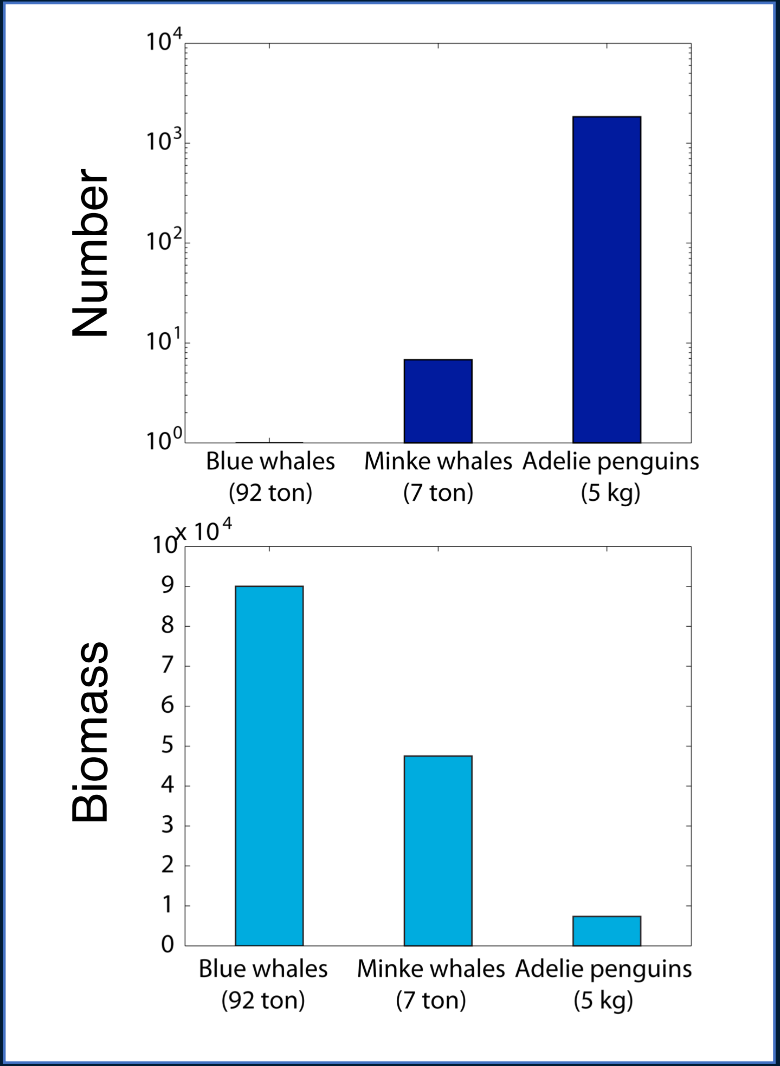
Biomass: Bigger is better

- Big animals do amazing things
  - High metabolic efficiency
    - Same food (krill) that supports one 92 ton blue whale
    - 7 minke whales or 1800 penguins
    - but, the total biomass would be less (1/2 or 1/10)
    - extra carbon would go to atmosphere

One Blue Whale's Food



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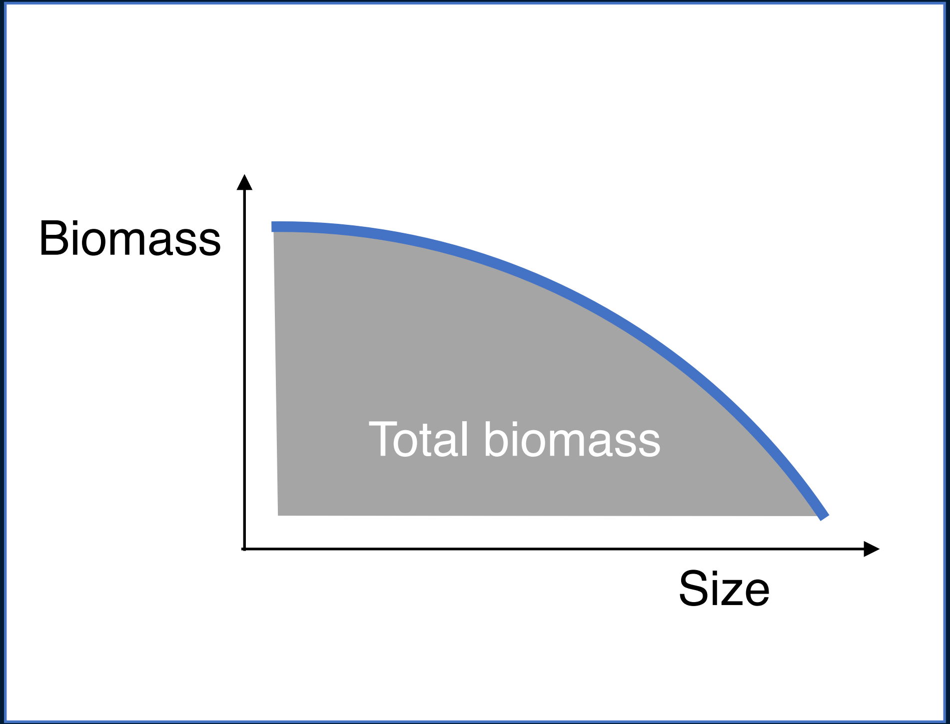
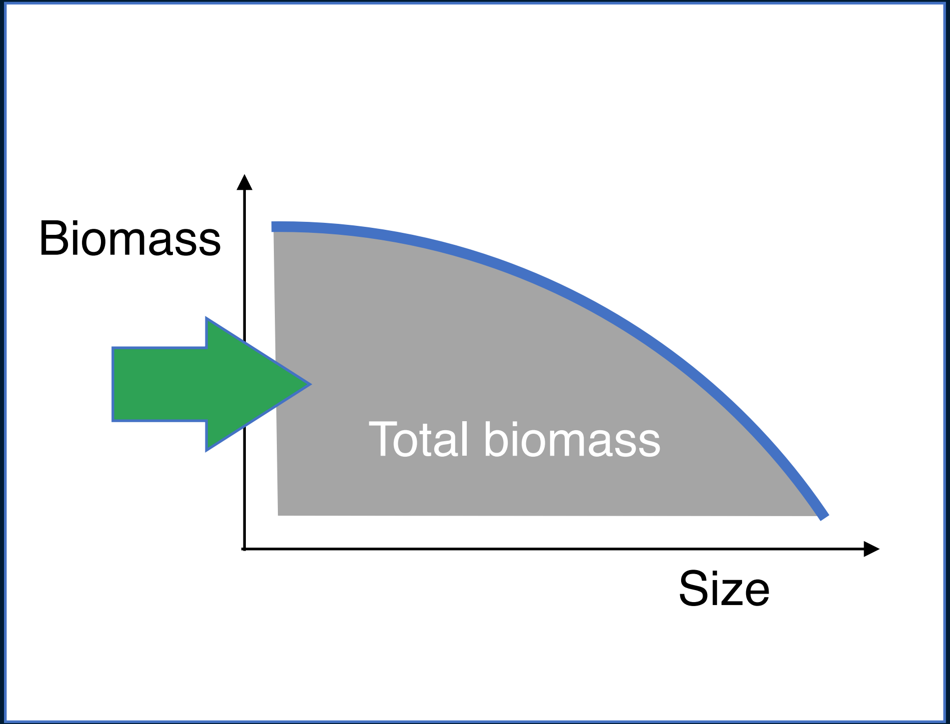
Fishing & Carbon Storage



Fishing & Carbon Storage



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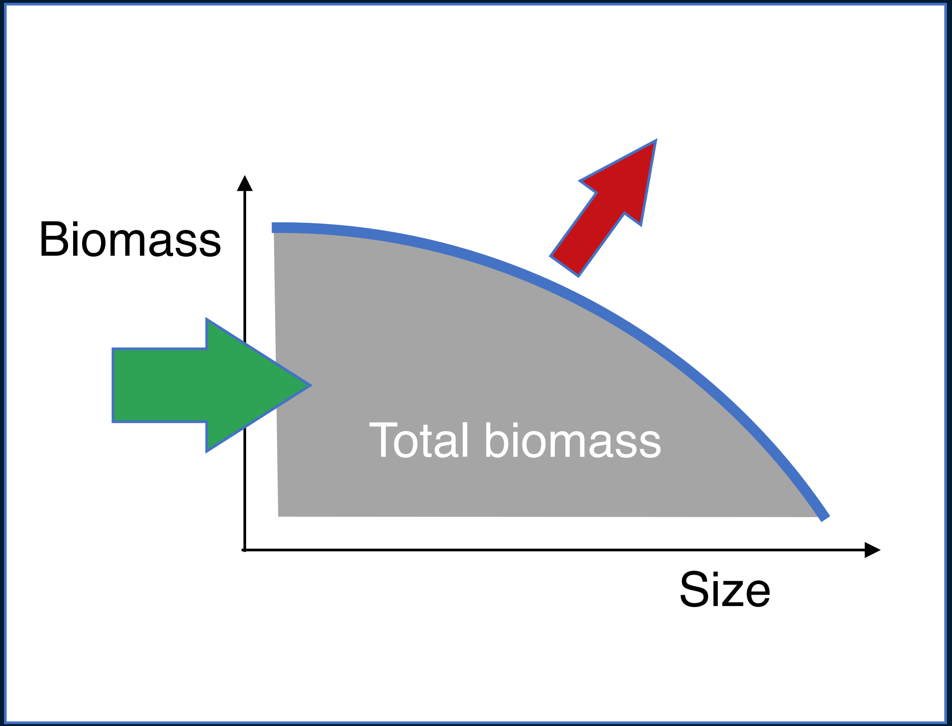
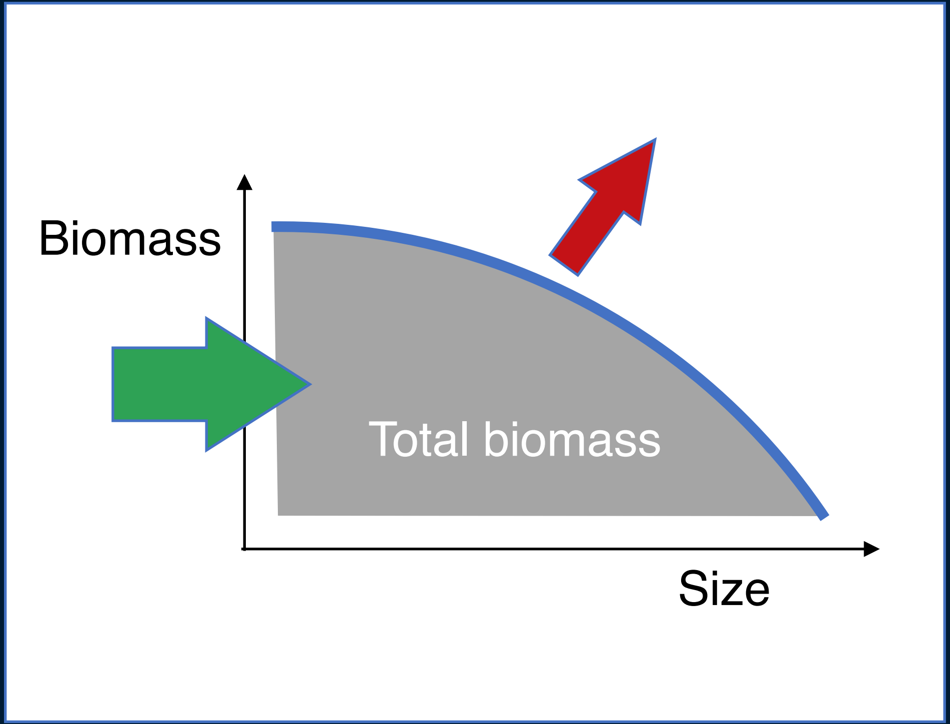
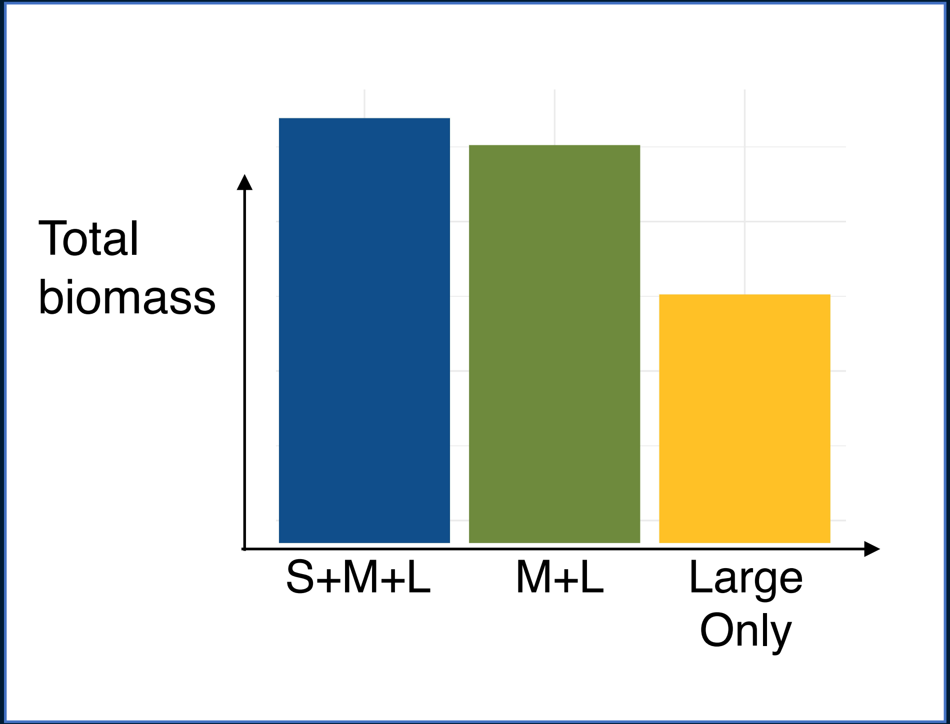
Fishing & Carbon Storage



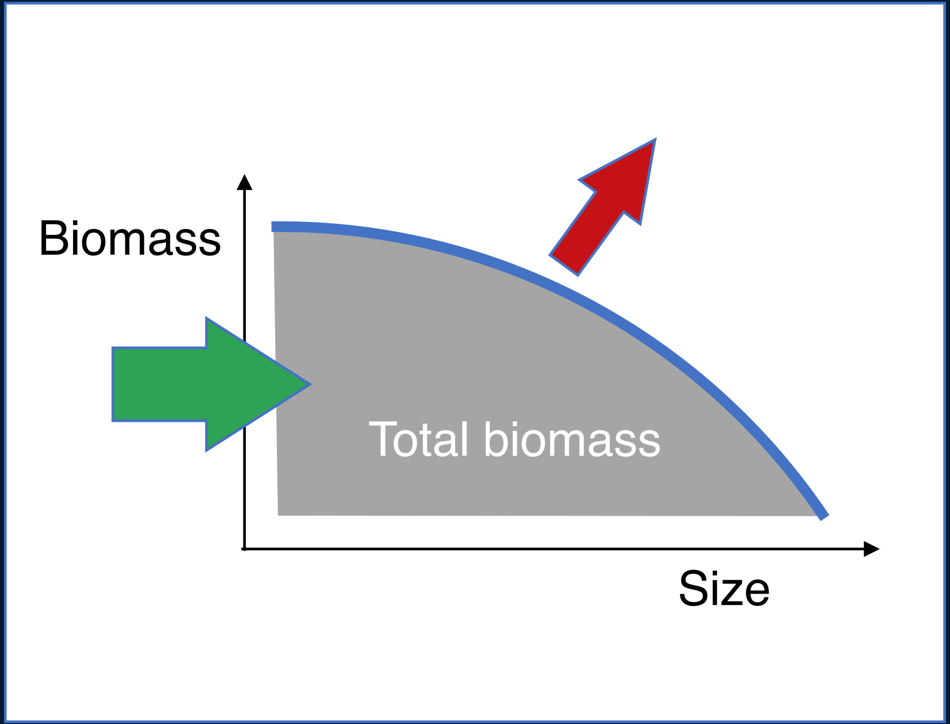
Fishing & Carbon Storage

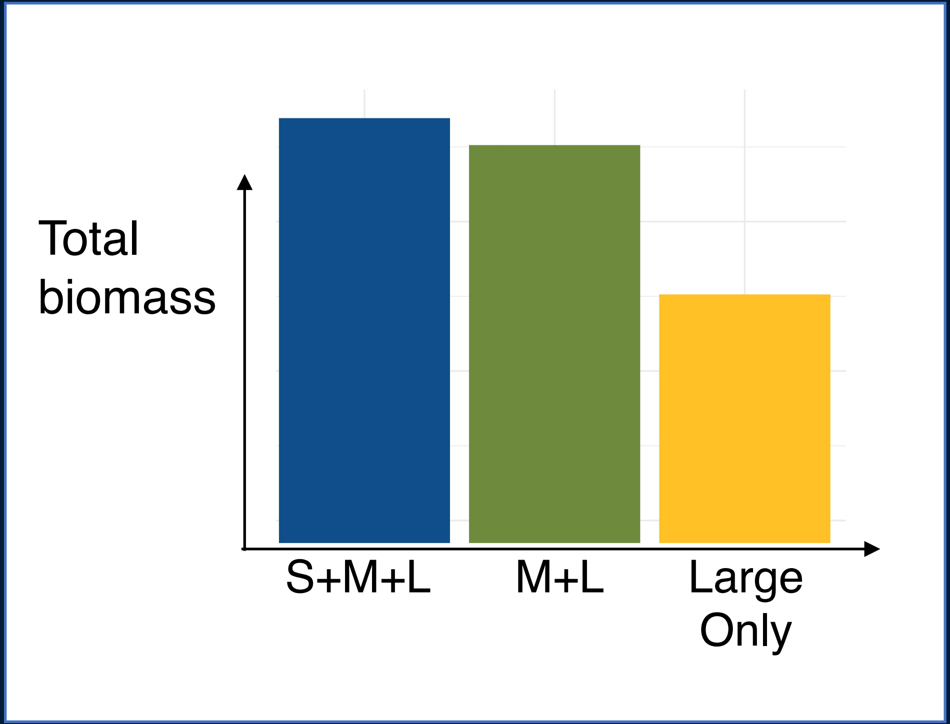




Falciani, Grigoratou, & Pershing (unpublished)

Fishing & Carbon Storage





- Bigger is better: preserving large fish keeps more carbon in the ecosystem

Falciani, Grigoratou, & Pershing (unpublished)

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Ocean Ecosystems and Carbon

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Ocean Ecosystems and Carbon

- Emerging theme: “bigger is better”
  - Package carbon, more efficient metabolism, connect ecosystems (surface & deep, eutrophic and oligotrophic)

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Ocean Ecosystems and Carbon

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- Likely small relative to microbes
  - But, benefits will accrue, especially in low-emissions world
- Goals are aligned:
  - Rebuilding benefits conservation, fisheries, and carbon goals
- Safe:
  - Relative to something like iron fertilization, outcomes are predictable

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Recommendations

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- Recommendations
    - Move beyond whales to fish

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  - Take a whole ecosystem perspective

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  - Consider how carbon markets could support conservation

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Recommendations

- Recommendations
  - Move beyond whales to fish
  - Take a whole ecosystem perspective
  - Consider how carbon markets could support conservation
  - Consider climate impacts on these processes

J. Bøtter, https://www.washington.edu

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Acknowledgements & Key References

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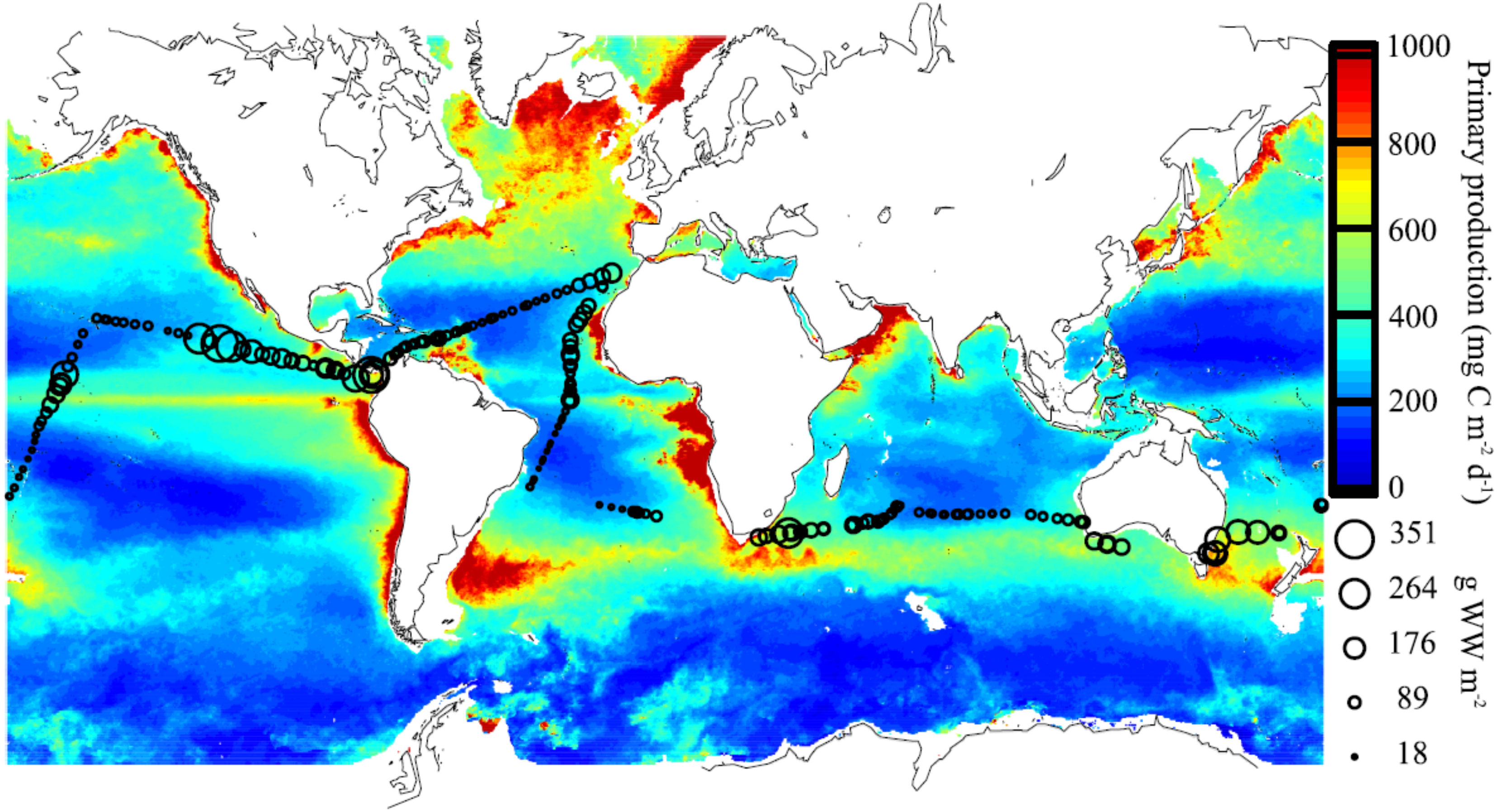
Mesopelagic fish and fisheries role in carbon removal and sequestration.

Ocean-based CDR Opportunities and Challenges

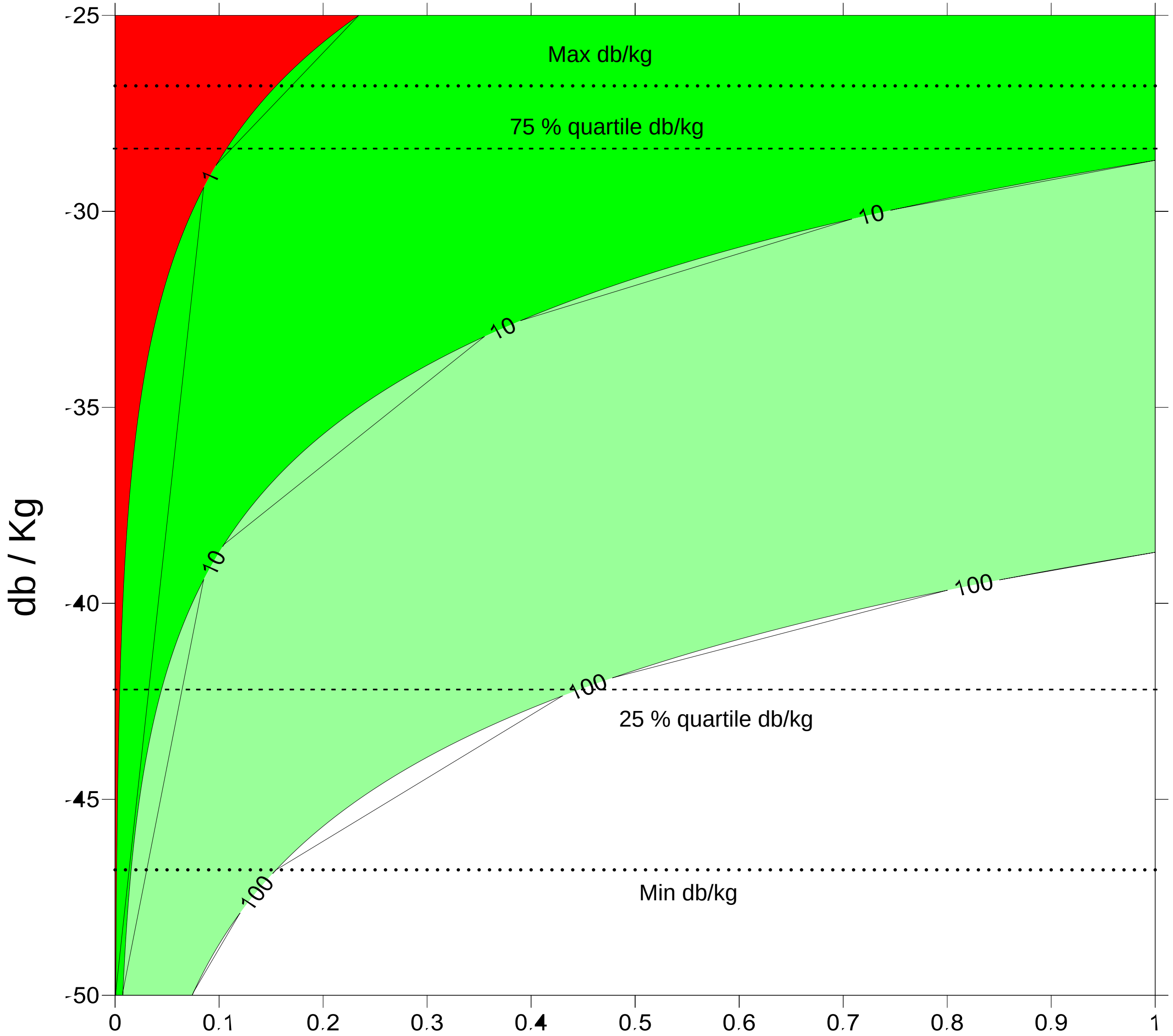
Part 3: Ecosystem Recovery & Seaweed Cultivation

Xabier Irigoien (26/02/2021)
AZTI – BRTA
Ikerbasque

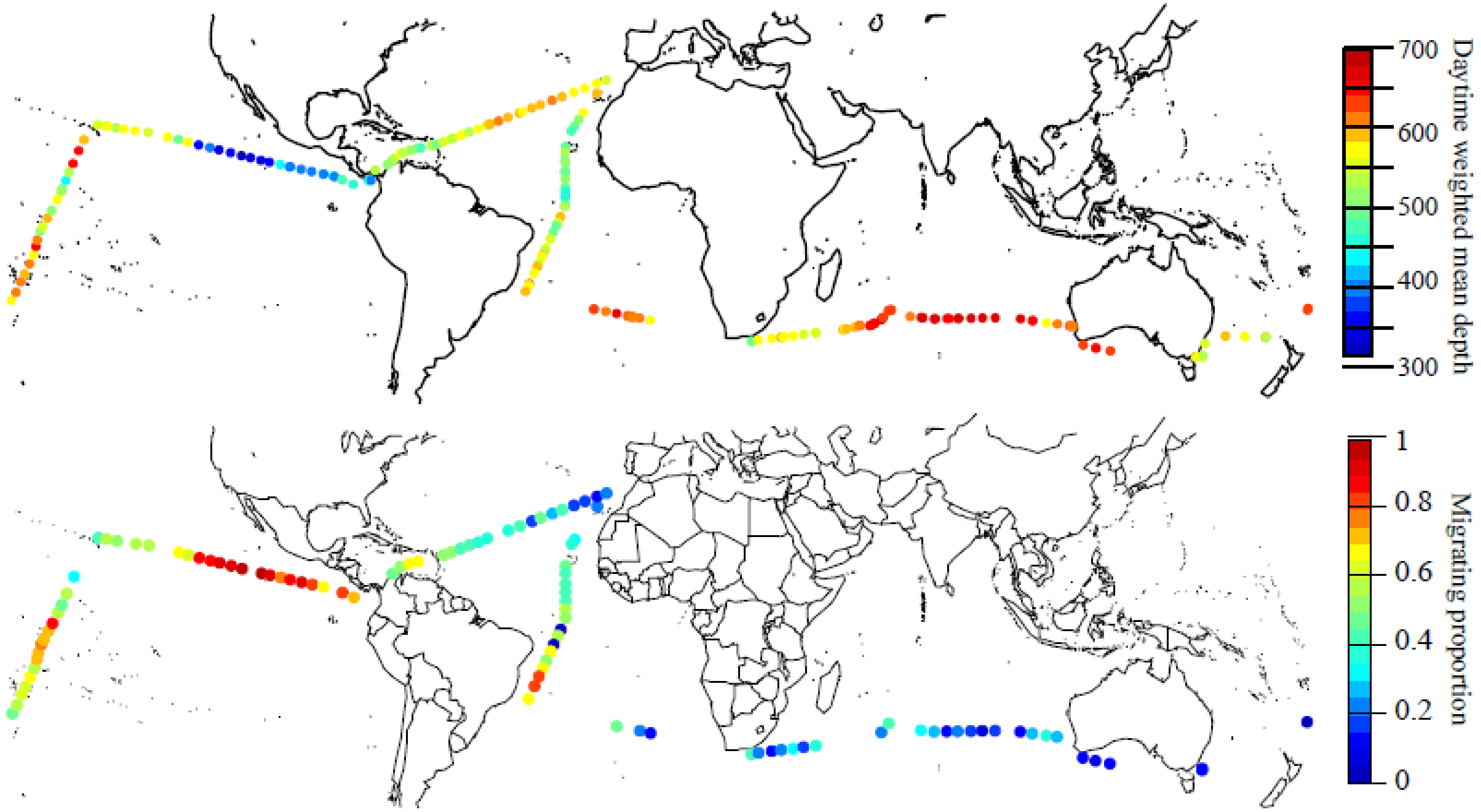
Malaspina Expedition



How many fish ?

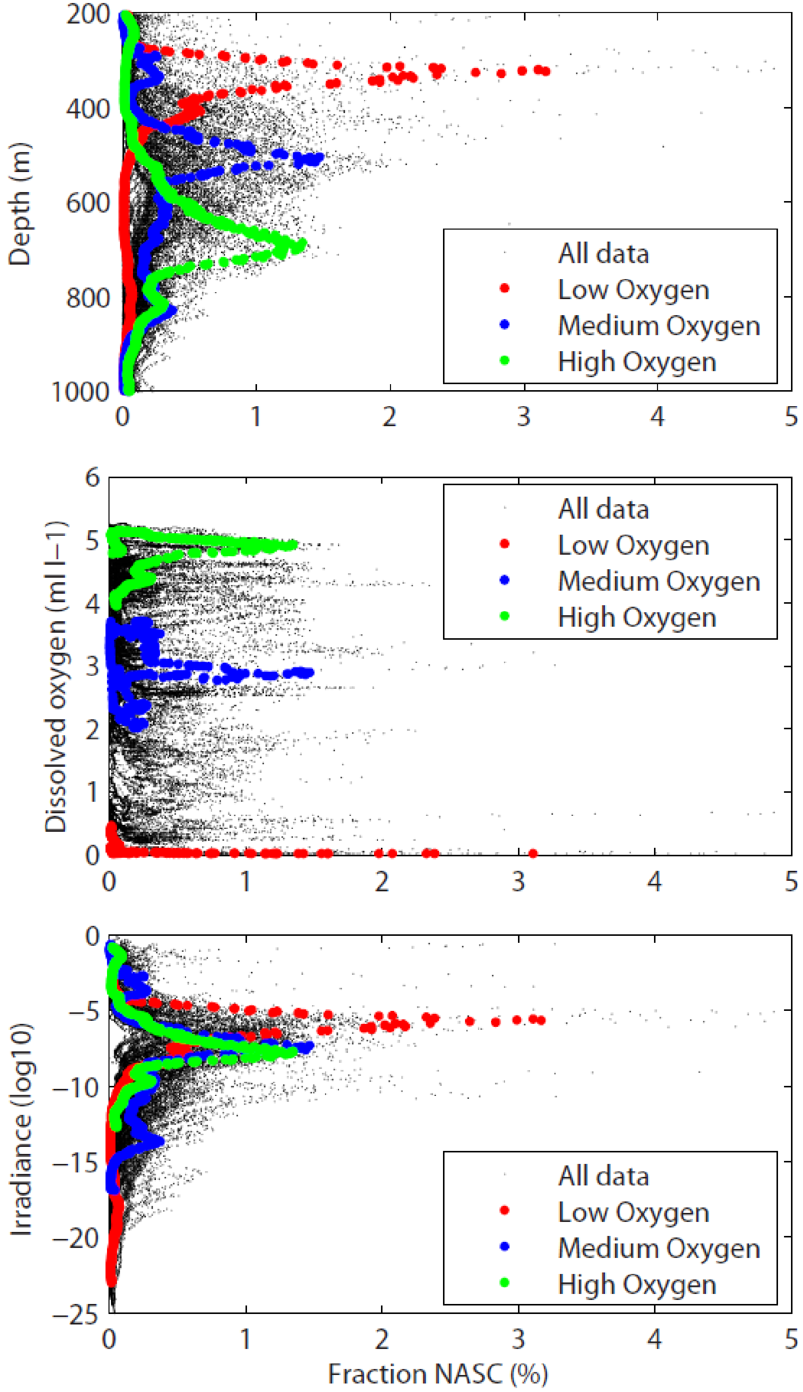


How Deep ?

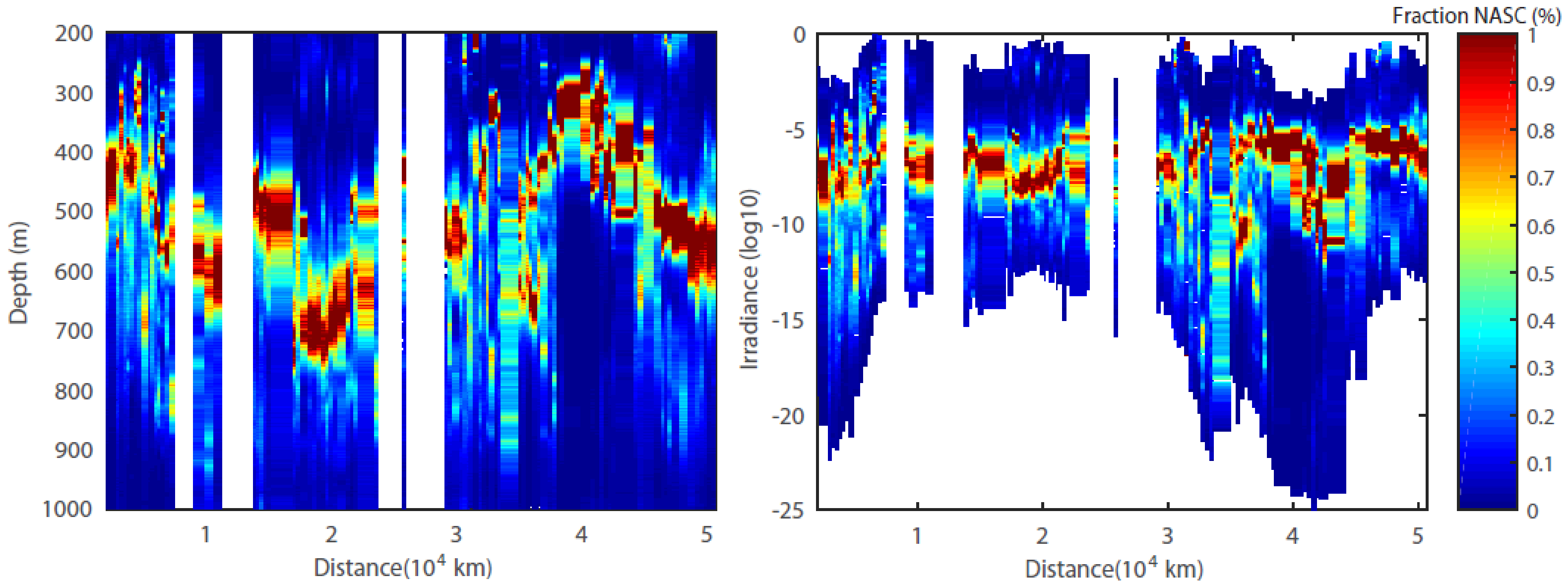


Klevjer et al., 2016

Why ?



Depth (m)
200
400
600
800
1000
0
1
2
3
4
5
All data
Low Oxygen
Medium Oxygen
High Oxygen
Dissolved oxygen (ml l−1)
6
5
4
3
2
1
0
Irradiance (log10)
−5
−10
−15
−20
−25
Fraction NASC (%)



Depth (m)
200
300
400
500
600
700
800
900
1000
Distance(10^4 km)
Irradiance (log10)
0
-5
-10
-15
-20
-25
1
2
3
4
5
Fraction NASC (%)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

Carbon flux: 35 mg C m-2d-1

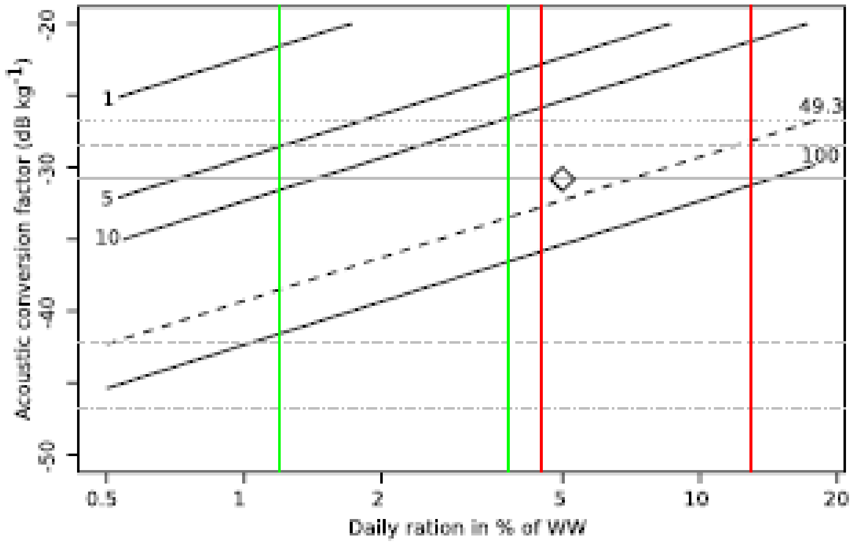


Figure 6. Contour plot of estimated carbon flux in mg C m^{-2} d^{-1} (black lines) as a function of acoustic conversion factor and ingestion, for an acoustic transport of 1000 m^2 nmi^{-2}. The sensitivity model assumes that all ingestion occurs in the epipelagic, that half the ingested carbon is transported to mesopelagic depths, and that the carbon constitutes 5% of the ingested wet weight. The black unbroken diagonal lines are contour lines of estimated carbon flux, delineating flux levels of 1, 5, 10 and 100 mg C m^{-2} d^{-1}. The black diagonal dashed line is the contour line of 49.3 mg C m^{-2} d^{-1}, corresponding to the global average of gravitational flux out of the epipelagic[37]. Horisontal gray dotted lines are maximum and minimum acoustic conversion values from literature as reported in Irigoien *et al.* 2014[5], dashed lines are 25 and 75 percentiles, and the grey unbroken line is the median value, all from from Irigoien *et al.* 2014. Green lines indicate range of daily rations reported for myctophids from temperate and subtropical regions[48] (range 1.2–3.8% of dry body weight, for simplicity we assume that WW to DW ratio is equal in myctophids and prey). Red lines indicate daily rations reported for subtropical and tropical species[48,49] (range 4.5–13% of dry body weight). Using the median acoustic conversion factor from[5], and a daily ration of 5% of WW, modelled carbon flux would be ~34.9 mg C m^{-2} d^{-1} (black diamond).

Klevjer et al., 2016

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Carbon flux anchovies fecal pellets: 251 mg C m-2d-1

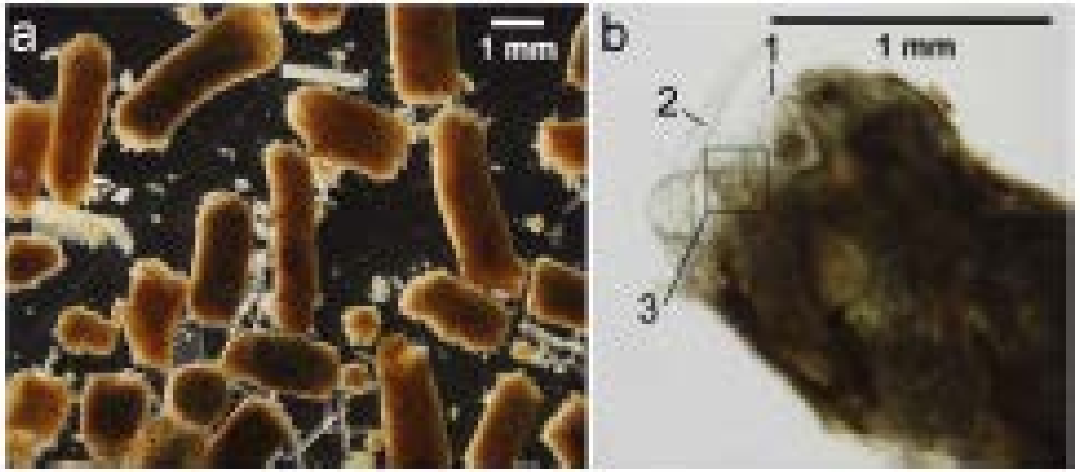


Figure 2 | Example fish fecal pellets collected in Santa Barbara Channel and used for analyses. Scale bar shown on individual panels. Copepod body parts are visible within the fish fecal pellet in the panel b: 1, swimming leg; 2, antenna; 3, furcal rami.

2,5 mg C m-2d-1 per 1 g wet weight fish in fecal pellets (Angel 1985).
90 million tonnes catches
225000 tonnes C

Rapidly sinking fecal pellets are an important component of the vertical flux of particulate organic matter (POM) from the surface to the ocean's interior; however, few studies have examined the role fish play in this export. We determined abundance, size, prey composition, particulate organic carbon/nitrogen (POC/PON), and sinking rates of fecal pellets produced by a forage fish, likely the northern anchovy, in the Santa Barbara Channel. Pellet abundance ranged from 0.1–5.9 pellets m^{-3}. POC and PON contents averaged 21.7 µg C $pellet^{-1}$ and 2.7 µg N $pellet^{-1}$. The sinking rate averaged 787 m d^{-1}; thus pellets produced at the surface would reach the benthos (~500 m) in <1 day. Estimated downward flux of fish fecal POC reached a maximum of 251 mg C m^{-2} d^{-1}. This is equal to or exceeds previous measurements of sediment trap POM flux, and thus may transport significant amounts of repackaged surface material to depth.

Saba and Steinberg 2012

Fisheries and mesopelagics, rough approaches

Fisheries:

2,5 mg C m-2d-1 per 1 g wet weight fish in fecal pellets. (Angel et al)

90 Million tonnes anual wild fish catches

225000 tonnes C

Mesopelagics

35 mg C m-2d-1

361900000 Km2 Ocean

12666500 tonnes C

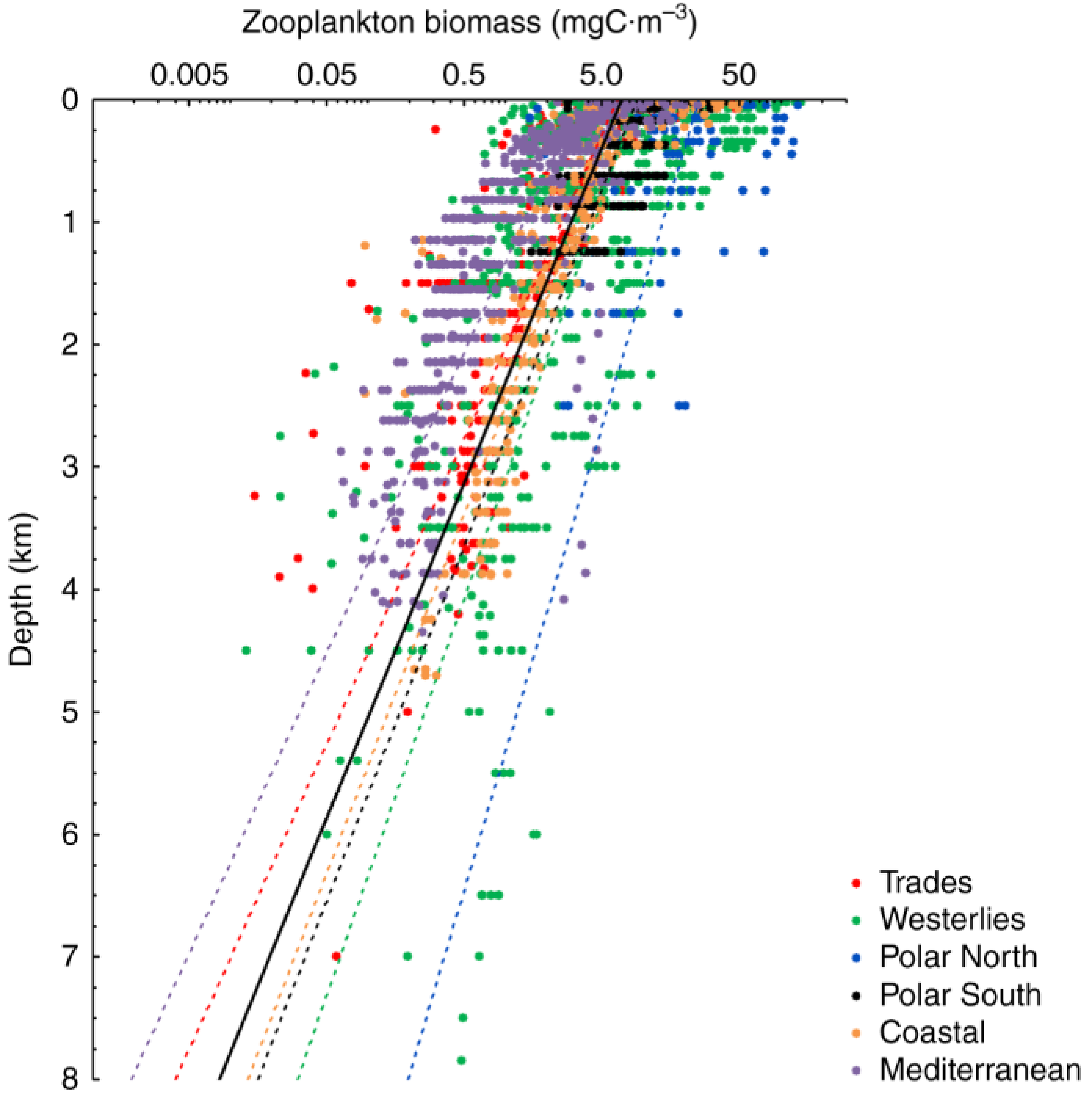
DO NOT TRUST THIS NUMBERS

Roughly fish could be contributing 5 to 25 million tonnes to carbon flux, fisheries would decrease 1 to 4 % of the direct flux

DO NOT TRUST THIS NUMBERS

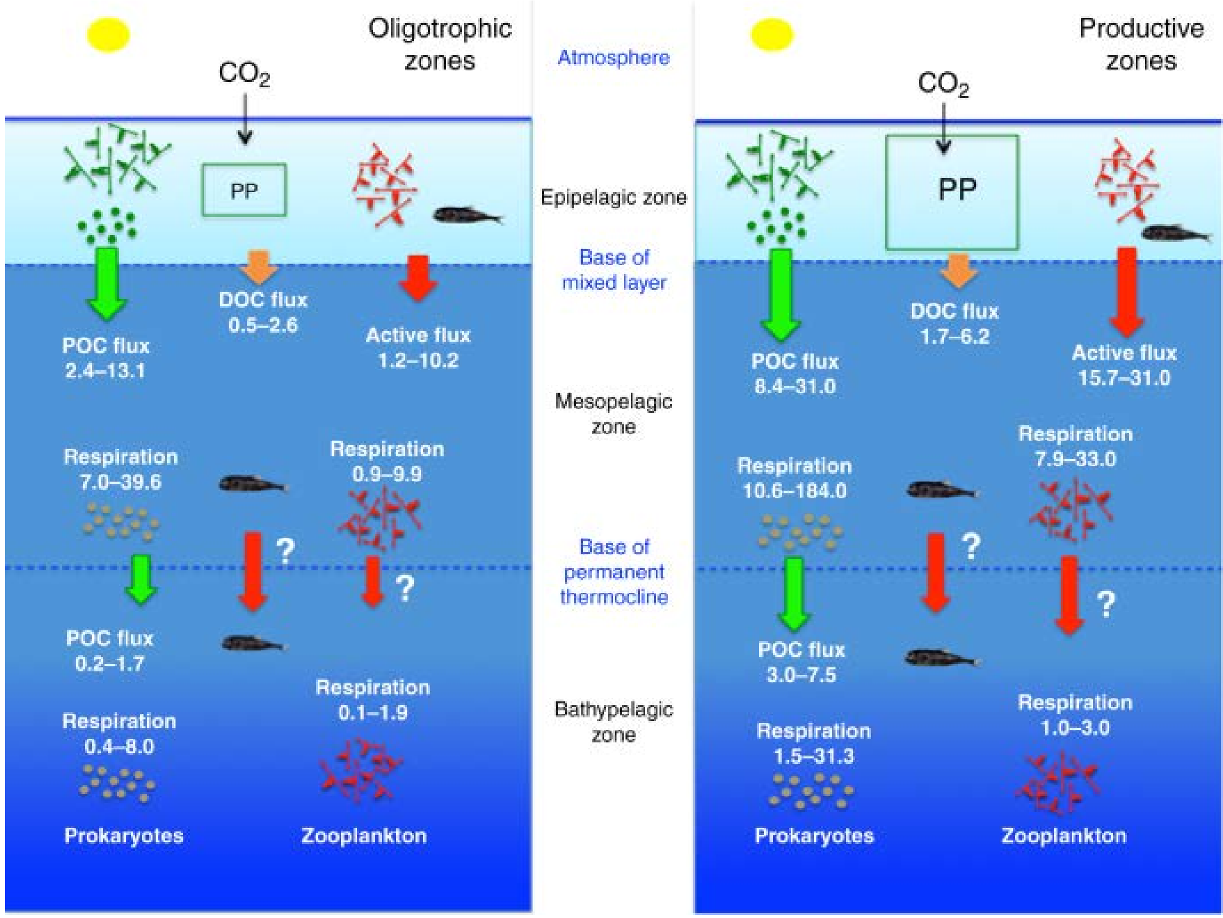
	Million Tonnes	fecal pellets mg C m-2d-1 per 1 g wt fish	Tonnes C
Catches	90	2,5	225000
Fish	2000	2,5	5000000
Fish	10000	2,5	25000000

Not only fish



Hernandez-Leon et al., 2020

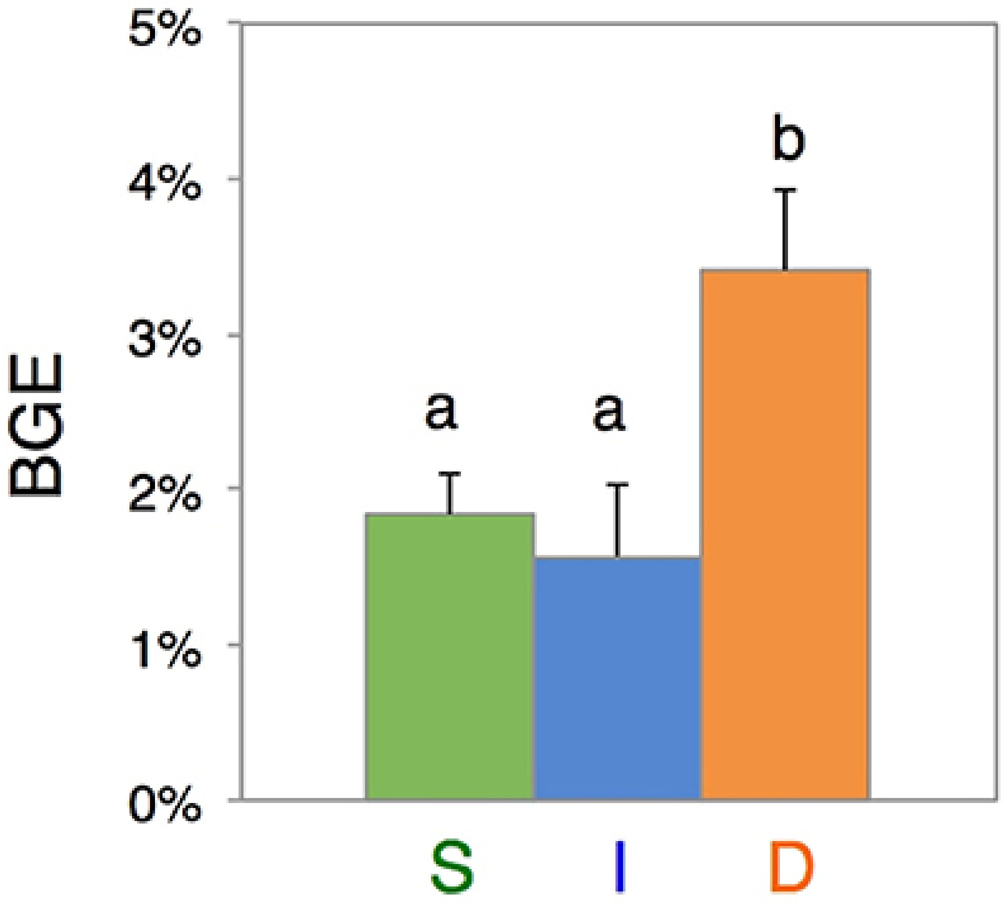
Synthesis of carbon export values (from the epipelagic towards the mesopelagic zone) and sequestration (from the mesopelagic towards the bathypelagic zone) of particulate organic carbon (POC, green arrows) flux, active flux due to migrant zooplankton, and micronekton (red arrows), and estimated dissolved organic carbon (DOC, orange arrows) flux (as 20% of POC flux, see text). Values are given in gC $m^{-2}\ y^{-1}$, to compare values in oligotrophic (left panel) and productive systems (right panel). POC and active fluxes are higher in productive zones, as expected, but active export flux is proportionally higher in productive zones as recently observed in the tropical and subtropical Atlantic Ocean[9]. Values of prokaryote and zooplankton respiration are also higher than POC, DOC, and active fluxes for both export and sequestration. Active sequestration flux is, at present, unknown (reflected by a question mark in both panels) and it should also explain, at least in part, the higher respiration rates in the bathypelagic zones. Finally, active sequestration flux and respiration by macrozooplankton and micronekton should tend to balance the budget (see text), and they are also represented as question marks in the Figure.



Hernandez-Leon et al., 2020

What happens with the carbon down there ?

Figure 4. Prokaryotic biomass incorporation. Bacterial growth efficiencies (BGE, %) estimated for each water layer: surface (S, green), intermediate (I, blue) and deep scattering layer (D, orange). BGE values were calculated for the same period of bacterial exponential growth phase and DOC decay in each experiment, ranging from 3.6 to 4.6 days. Different lower case letters represent statistically significant differences ($P < 0.05$, *post-hoc* Fisher LSD test).



Calleja et al., 2018

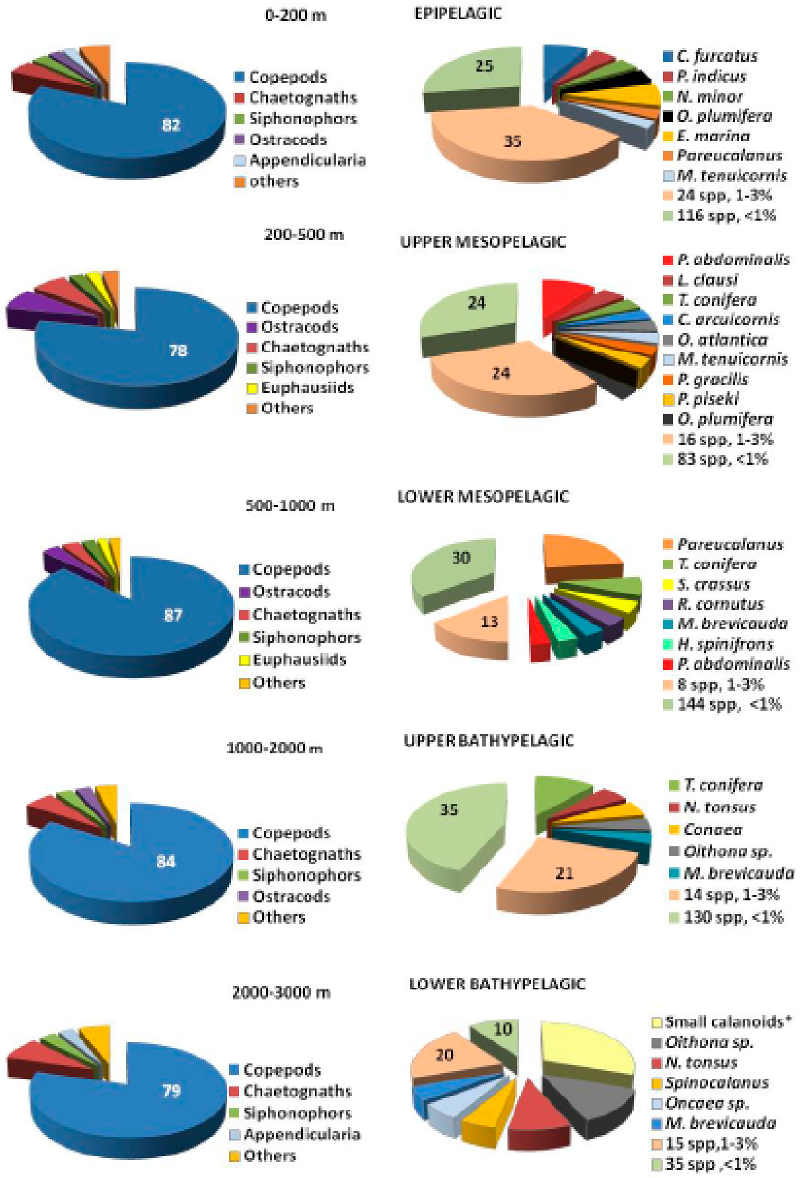


Figure 4. Relative abundance of main zooplankton groups (%), and dominant copepods (*Clausocalanus furcatus*, *C. arcuicornis*, *Paracalanus indicus*, *Nannocalanus minor*, *Neocalanus tonsus*, *Euchaeta marina*, *Mesocalanus tenuicornis*, *Subeucalanus crassus*, *Metridia brevicauda*, *Heterorhabdus spinifrons*, *Rhincalanus cornutus*, *Oithona plumifera*, *O. atlantica*, *Pleuromamma abdominalis*, *P. gracilis*, *P. piseki*, *Lucicutia clausi*, *Triconia conifera* and small calanoids* as possible contaminants) found at each depth layer (averaged across all stations sampled).

Fernández de Puelles et al. 2019

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Questions ?

Enhancing Blue Carbon actions: Lessons from coastal wetlands

Image Candy Feller

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

Catherine Lovelock
c.lovelock@uq.edu.au

Agenda

1) Factors that accelerate implementation of Blue Carbon projects and activities in coastal wetlands
2) Impediments
3) Conclusions



Science linked to activities

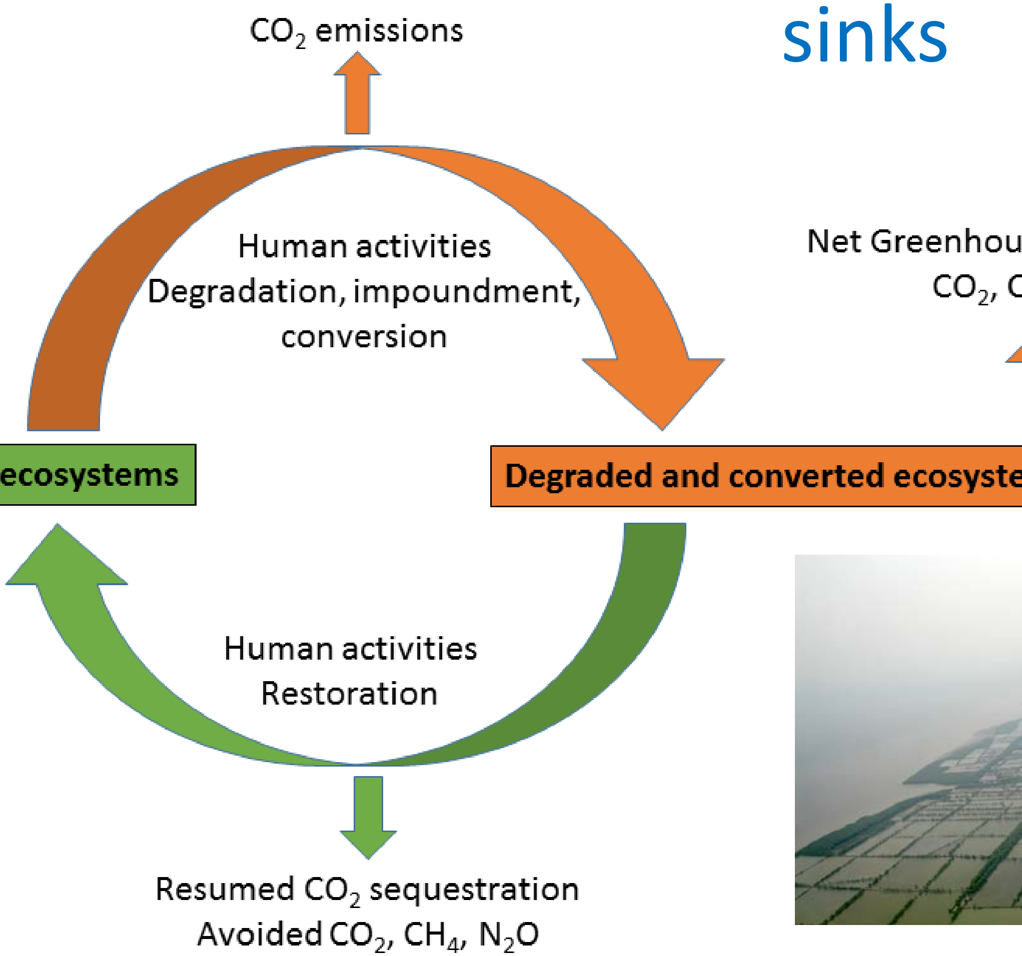
Conservation

Avoid CO_2 emissions

Restoration

Restore the CO_2 sinks

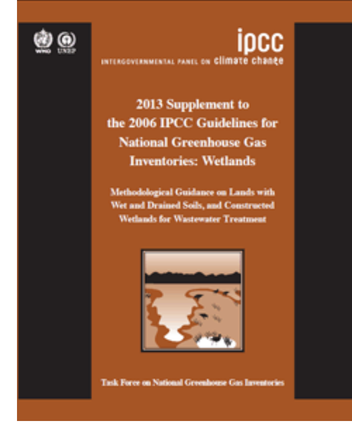
Figure 2.2 Mangrove ecosystem services support human well-being.



Lovelock et al. 2018

1) Factors that accelerate blue carbon activity in coastal wetlands

IPCC Guidance



- IPCC guidance to estimate GHG emissions/removals compels countries to include coastal wetlands in GHG inventories
- GHG guidance increases incentives for governments
- Knock-on effects , e.g. Provides a set of accepted “emission factors”, which can inform voluntary carbon market methods (e.g. Verified Carbon Standard; Emission Reduction Fund)

- “33rd Session (December 2010, Cancun), the Subsidiary Body for Scientific and Technological Advice (SBSTA of UNFCCC) invited the IPCC: To undertake further methodological work on wetlands…………….“
- IPCC Wetland Supplement completed 2013 – “recommended” all nations use in 2018

1) Factors that accelerate blue carbon activity in coastal wetlands

Synergistic policies

- Climate change adaptation (see NDCs)
- Biodiversity
- Water quality
- Livelihoods

SUSTAINABLE DEVELOPMENT GOALS

Image CSIRO

Image Gov QLD

1) Factors that accelerate blue carbon activity in coastal wetlands

Capacity

- Immense enthusiasm for Blue Carbon has led to wide engagement and increases in knowledge and capacity globally, across sectors

Image- IORA

2) Impediments

Appropriate finance

- Small projects (community led) are often not large enough for some investors (>$2 million) (and may not deliver desired ecosystem services)
- Large projects are prone to failure, corruption, social license
- For investors, restoration may be less favourable for carbon payments than conservation (e.g. MPAs) (incremental *vs.* one off payment)
- Uncertainty in benefits of investing – returns from carbon and other outcomes

Image - https://narei.org.gy/tag/restoration/

Image – Ben Brown

Techniques and methods

- Activities have high costs
- Projects are often small scale ("pilots")
- Monitoring and evaluation/verification - high costs

Image John Statton

Uncertainty

- Science – e.g. uncertain seagrass extent, levels of CO_2 emissions with with seagrass degradation, and links of C gains to actions on land
- Carbon rights – land owners *vs*. managers?
- Land tenure – intertidal zone can be contested
- Climate change impacts
  - Gains and/or losses - identifying important factors
  - Adequacy of MPAs – thermal impacts – migrating ecosystems

Image Richard Unsworth

3) Conclusions

- Assembling the scientific evidence, “activity” based
- Synergies with other policy priorities – attractiveness building resilience
- Influence governments: UNFCCC - COP/SBSTA and the IPCC – GHG inventories for oceans? Other options (Energy, Industry, Agriculture)
- Develop workable, inexpensive methods (tech. innovations)
- Timelines
- Climate change impacts – thermal events; MPAs/restoration for the future


Image Glenn Holmes

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