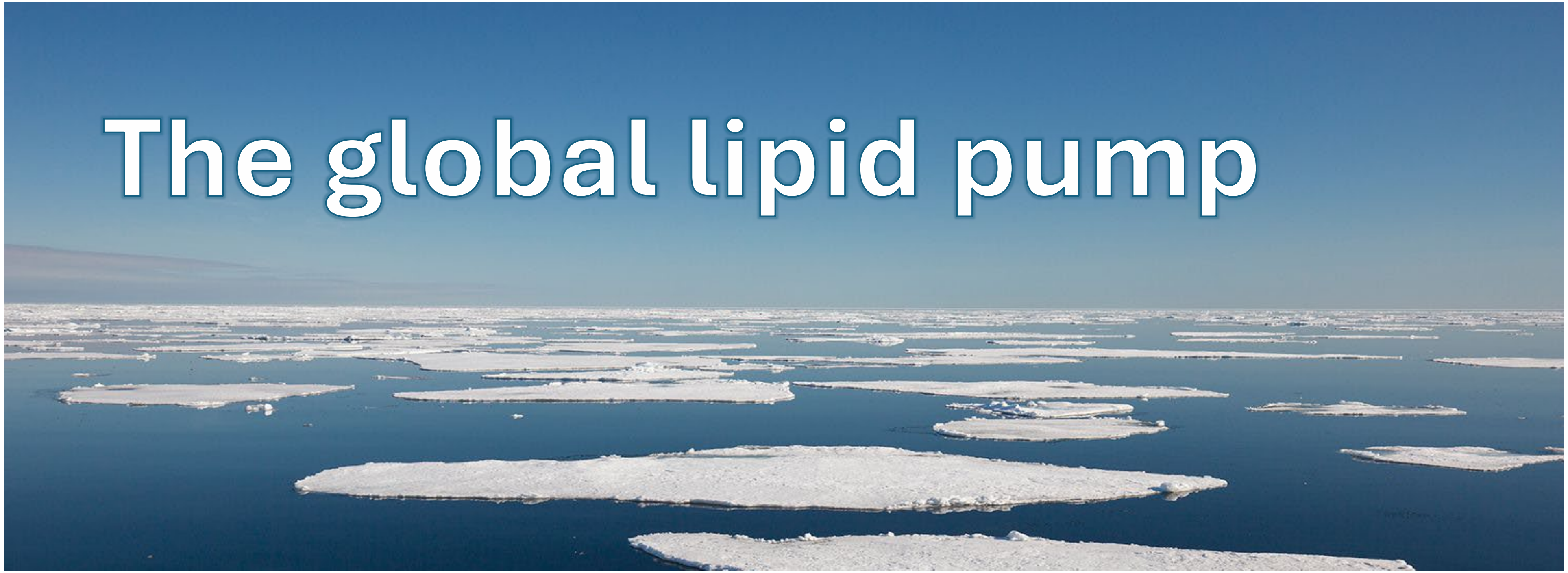
The global lipid pump



André Visser, Sigrún Jónasdóttir and Jérôme Pinti

Centre for Ocean Life
VKR Centre of Excellence

DTU Aqua
National Institute of Aquatic Resources

University of Delaware

Ocean-ICU

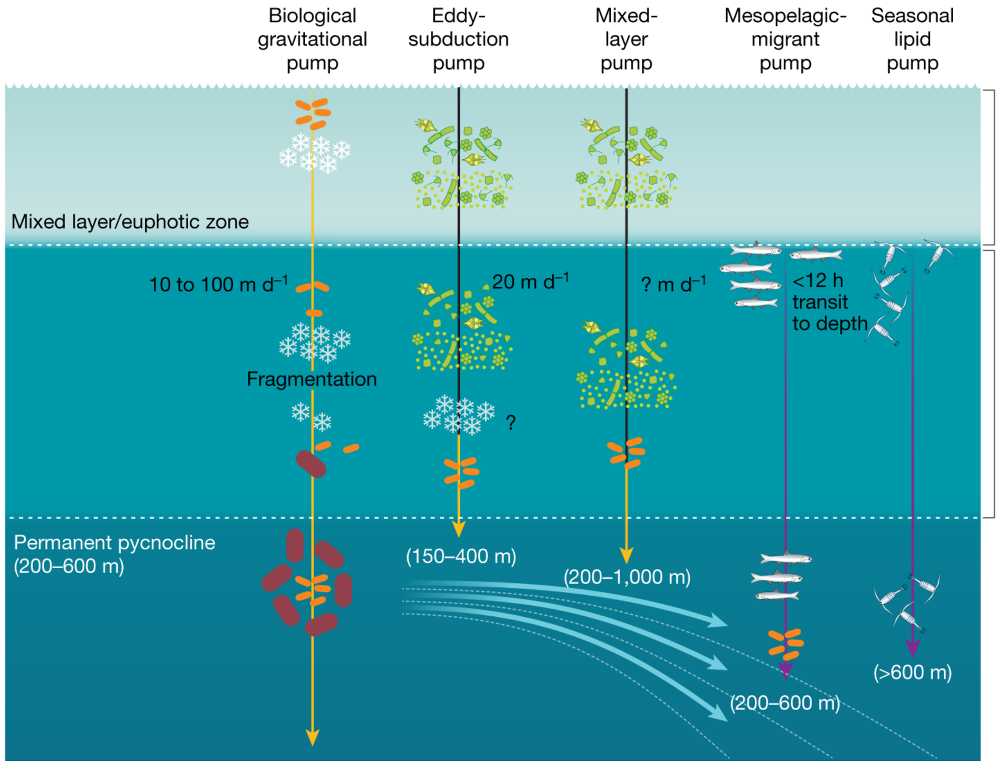
BioEcoOcean

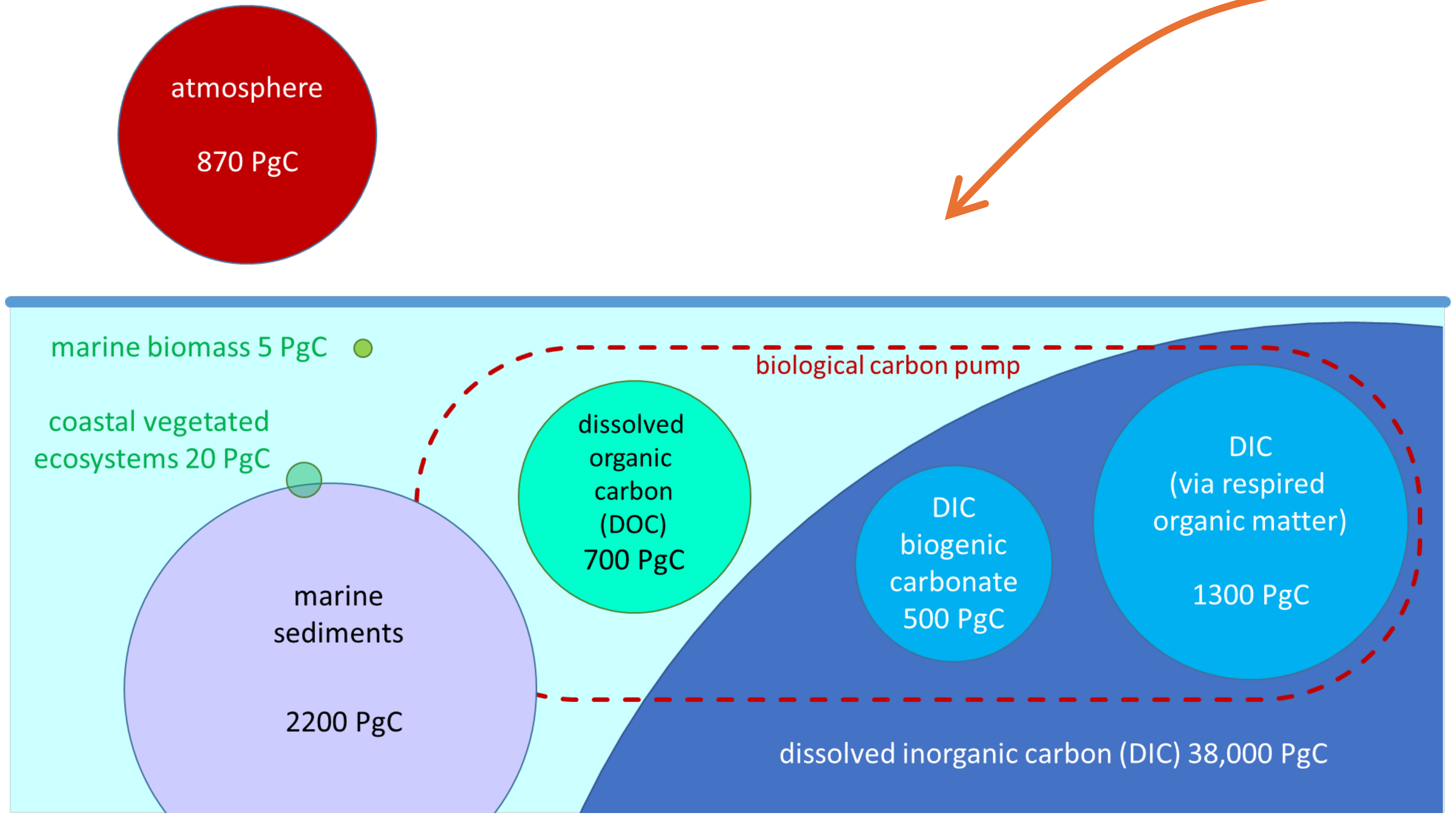
ECOTIP

Gordon and Betty Moore Foundation

Simons Foundation

The global lipid pump





Boyd, P.W., Claustre, H., Levy, M., Siegel, D.A. and Weber, T., 2019. Multi-faceted particle pumps drive carbon sequestration in the ocean. Nature, 568(7752), pp.327-335.

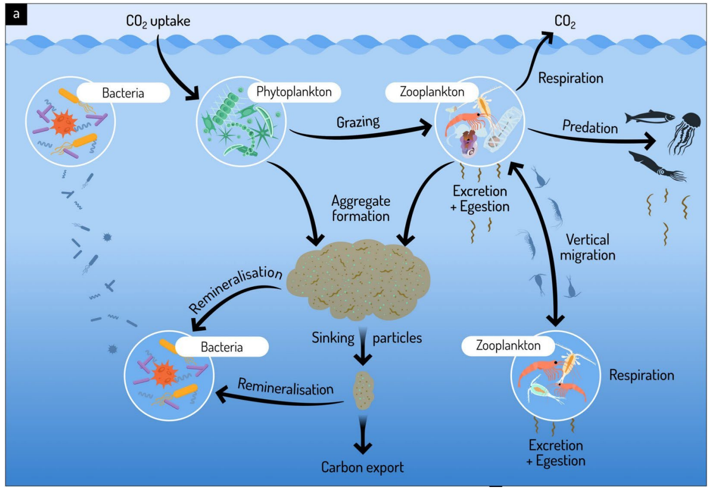
Carter et al 2021. Preformed properties for marine organic matter and carbonate mineral cycling quantification. *Global Biogeochemical Cycles*

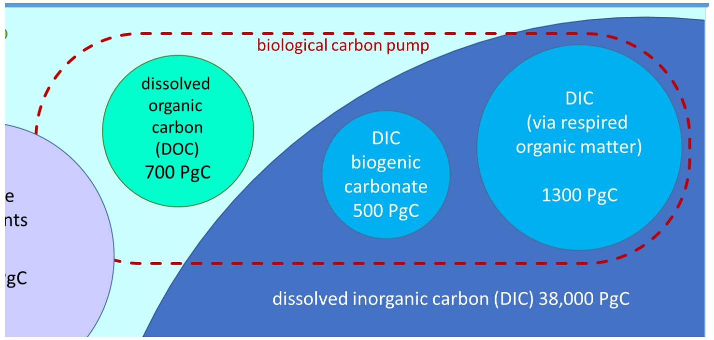
Visser AW (submitted) Residence Times and Legacy of Biogenic Carbon in Ocean Reservoirs. PNAS

The biological carbon pump:
Carbon Export, Carbon Sequestration and Residence Time

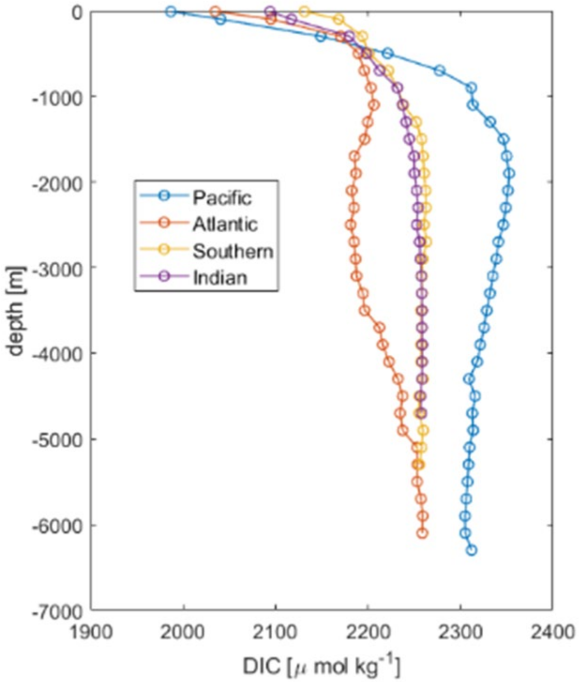
surface ocean

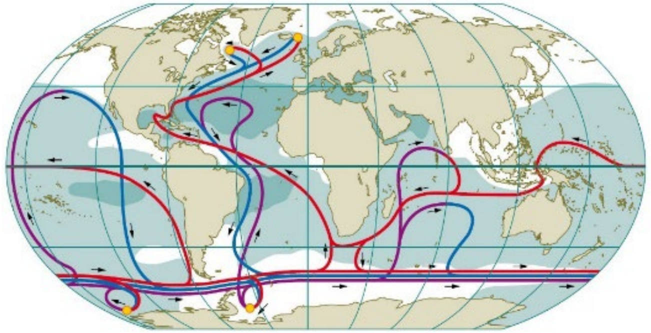
10 PgC / yr

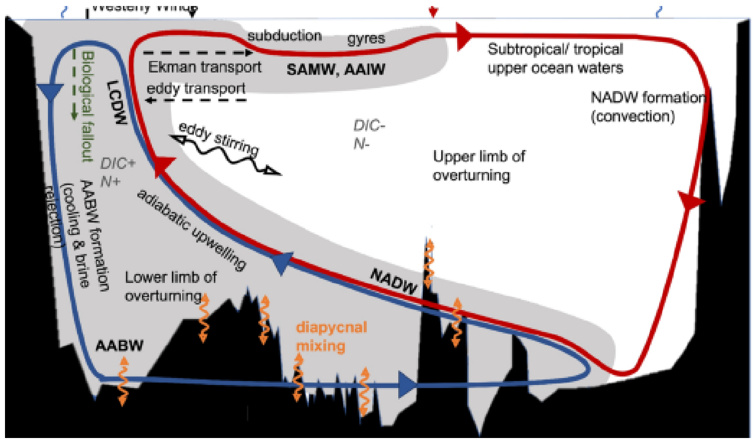




1300 PgC



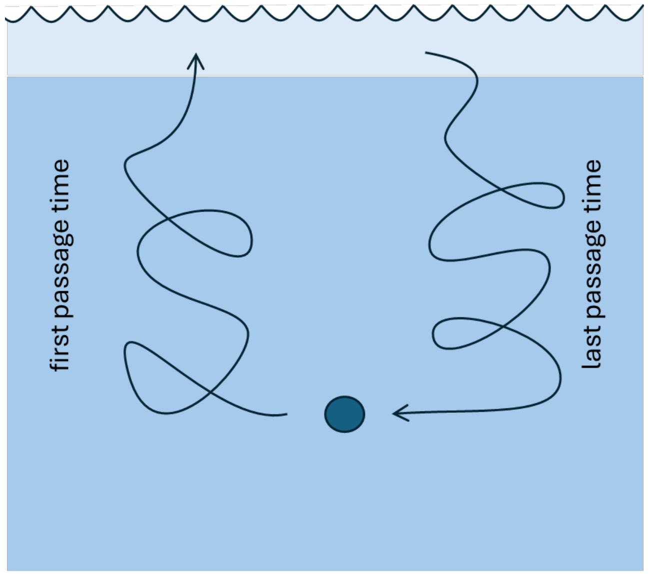


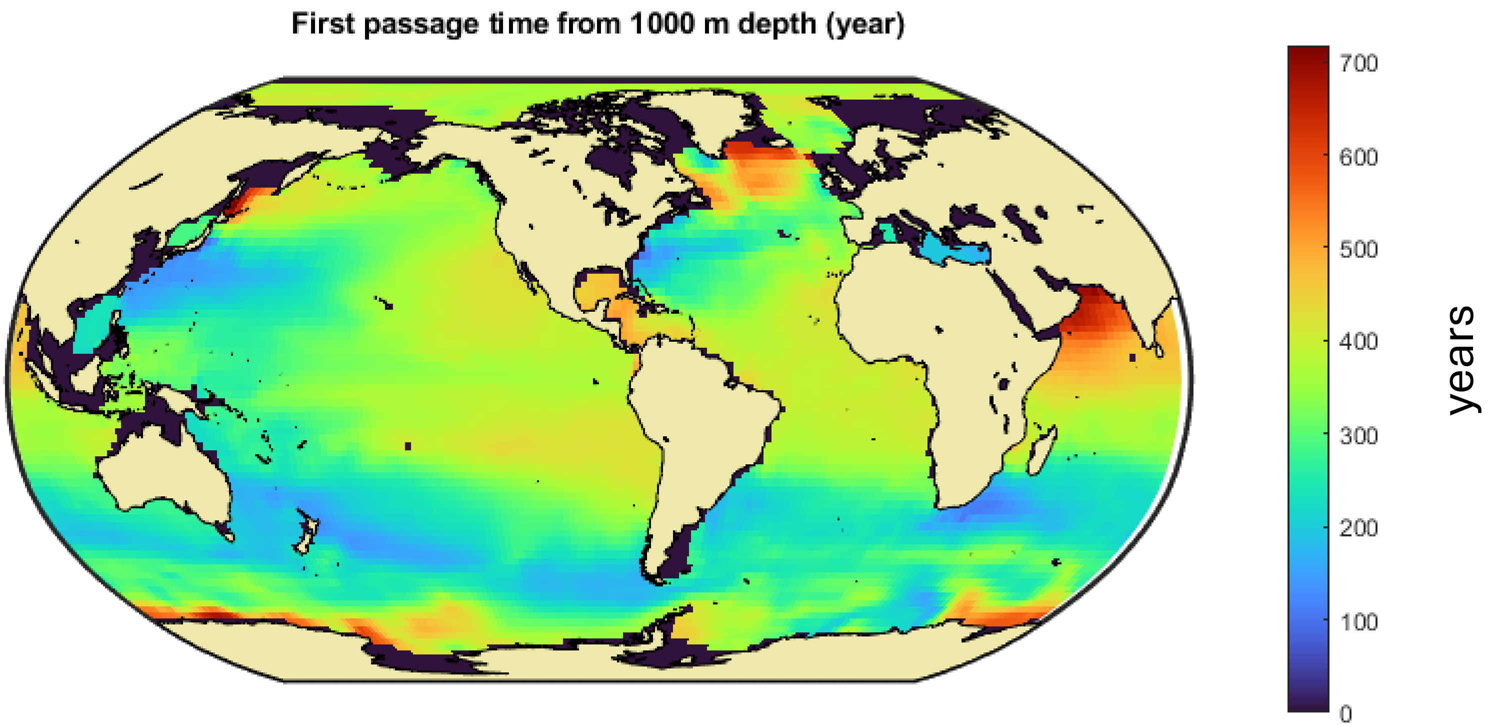


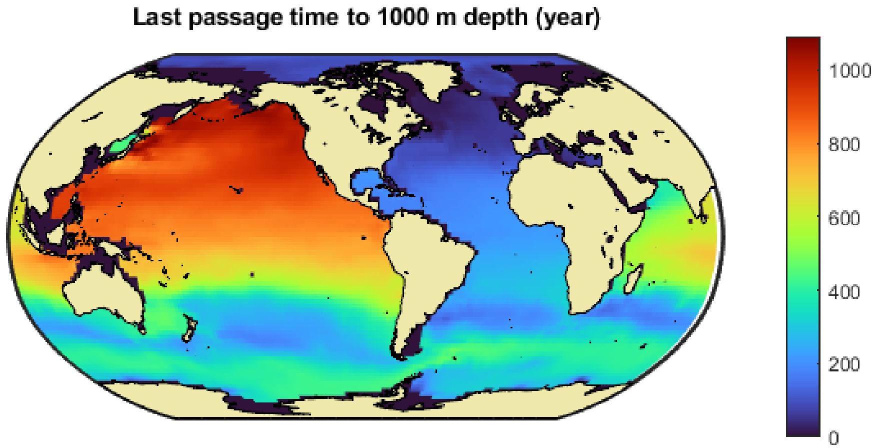
residence time

$$\frac{1300\ PgC}{10\ PgC/yr} = 130\ yr$$

How long Carbon stays in the ocean's interior if it is injected at 1000m depth?





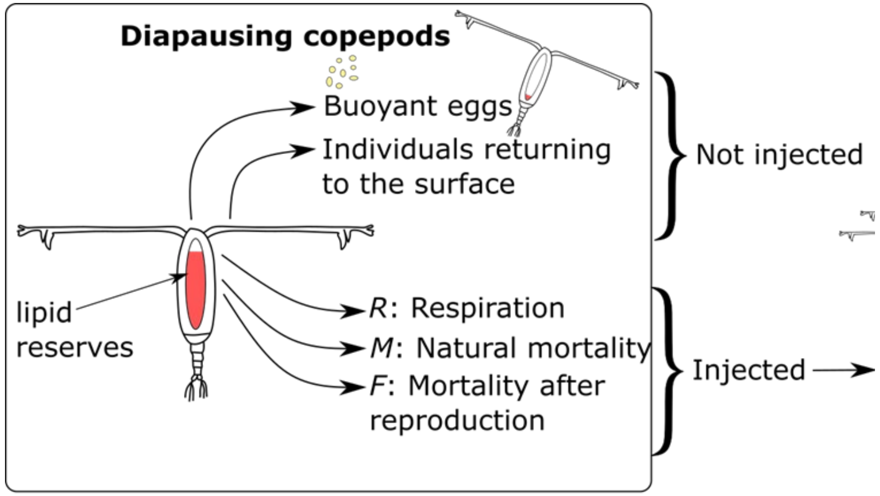


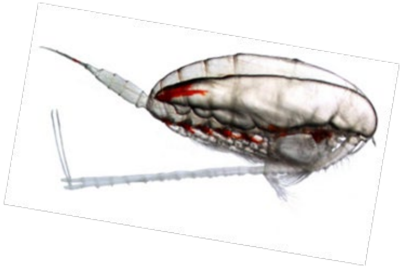
Transport matrix

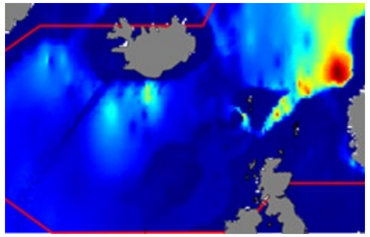
Generated with the OCIM ocean circulation model

Pinti, J., Visser, A.W., Serra-Pompei, C., Andersen, K.H., Ohman, M.D. and Kiørboe, T., 2022. Fear and loathing in the pelagic: How the seascape of fear impacts the biological carbon pump. *Limnology and Oceanography*, *67*(6), pp.1238-1256.

Method

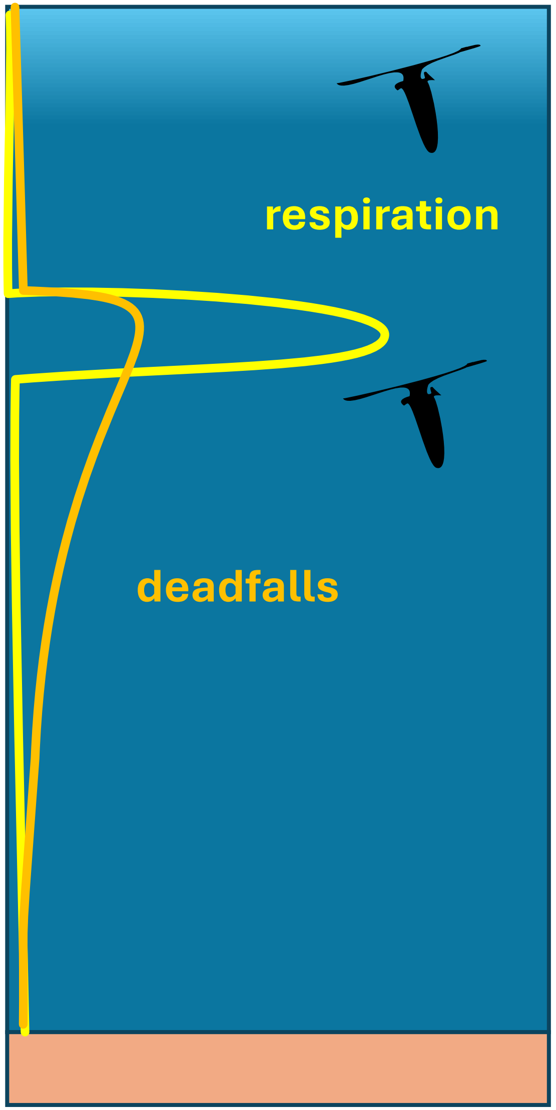






Target species
abundance, distribution, size/stage
diapause
depth, duration, mortality
life history

DIC injection
[gC m^{-3} day^{-1}]



LIMNOLOGY and OCEANOGRAPHY
ASLO
Limnol. Oceanogr. 9999, 2023, 1–14
© 2023 The Authors. Limnology and Oceanography published by Wiley Periodicals LLC on behalf of Association for the Sciences of Limnology and Oceanography.
doi: 10.1002/lno.12335

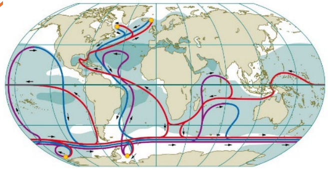
The global contribution of seasonally migrating copepods to the biological carbon pump

Jérôme Pinti[1*] Sigrún H. Jónasdóttir[2] Nicholas R. Record[3] André W. Visser[2,4]

Transport matrix

Sources and sinks

$$\frac{d\mathbf{c}}{dt} + \mathbf{Q}\,\mathbf{c} = \mathbf{s}$$



Tracer concentration

Steady-state equilibrium concentration

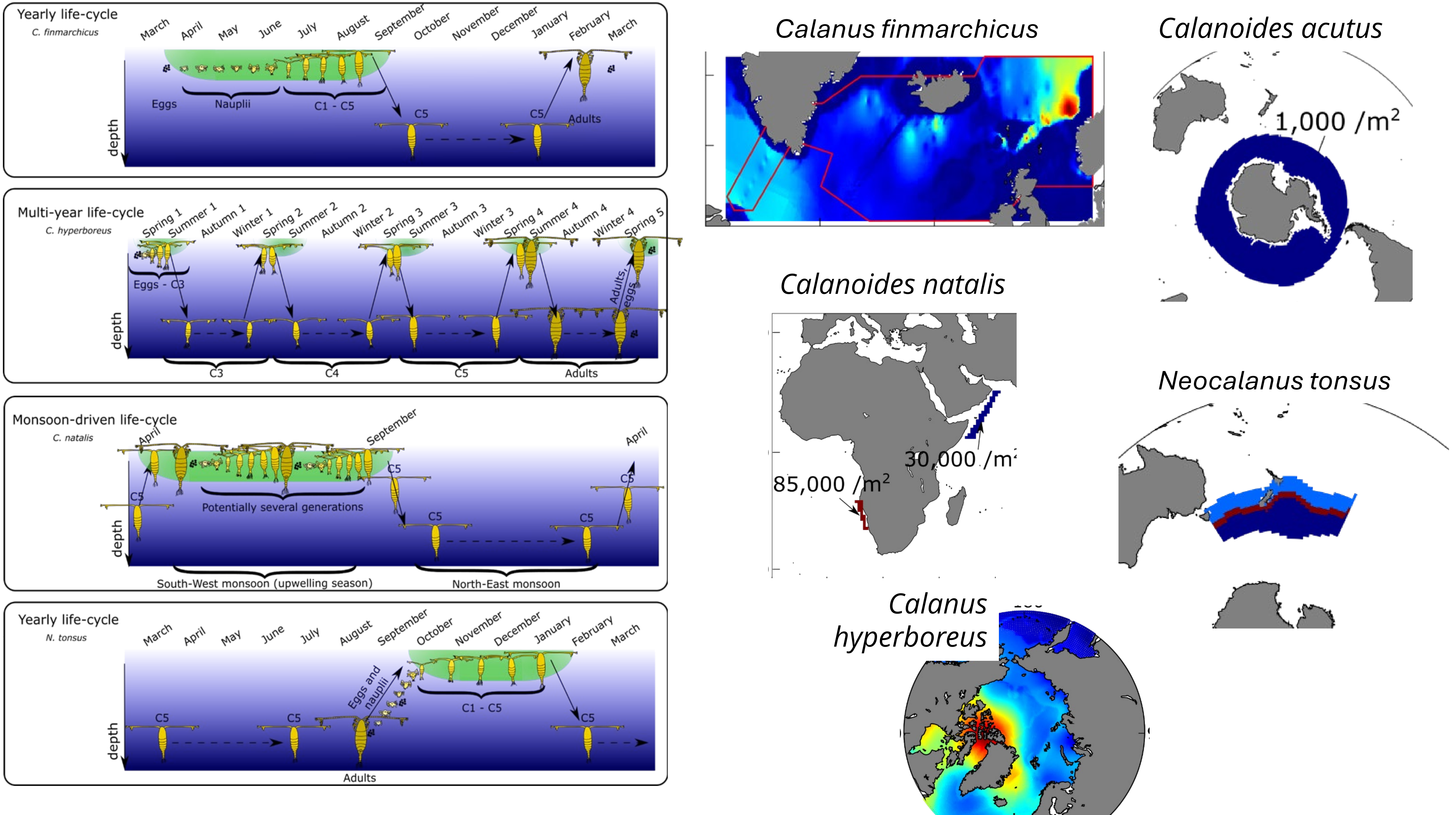
$$\mathbf{c}^* = \mathbf{Q}^{-1}\mathbf{s} \quad \text{with} \quad \mathbf{c}^*(z=0) = 0$$

Integrating equilibrium concentration

$$C_{seq} = \mathbf{c}^* \cdot \mathbf{V}$$

Sequestration time scale

$$T_{seq} = C_{seq} / (\mathbf{s} \cdot \mathbf{V})$$


Yearly life-cycle
C. finmarchicus
March
April
May
June
July
August
September
October
November
December
January
February
March
Eggs
Nauplii
C1 - C5
C5
C5
Adults
depth
Multi-year life-cycle
C. hyperboreus
Spring 1
Summer 1
Autumn 1
Winter 1
Spring 2
Summer 2
Autumn 2
Winter 2
Spring 3
Summer 3
Autumn 3
Winter 3
Spring 4
Summer 4
Autumn 4
Winter 4
Spring 5
Eggs - C3
Adults, eggs
depth
C3
C4
C5
Adults
Monsoon-driven life-cycle
C. natalis
April
September
April
C5
C5
C5
C5
C5
Potentially several generations
depth
South-West monsoon (upwelling season)
North-East monsoon
Yearly life-cycle
N. tonsus
March
April
May
June
July
August
September
October
November
December
January
February
March
C5
C5
Eggs and nauplii
C1 - C5
C5
depth
Adults
Calanus finmarchicus
Calanoides acutus
1,000 /m²
Calanoides natalis
30,000 /m²
85,000 /m²
Neocalanus tonsus
Calanus hyperboreus

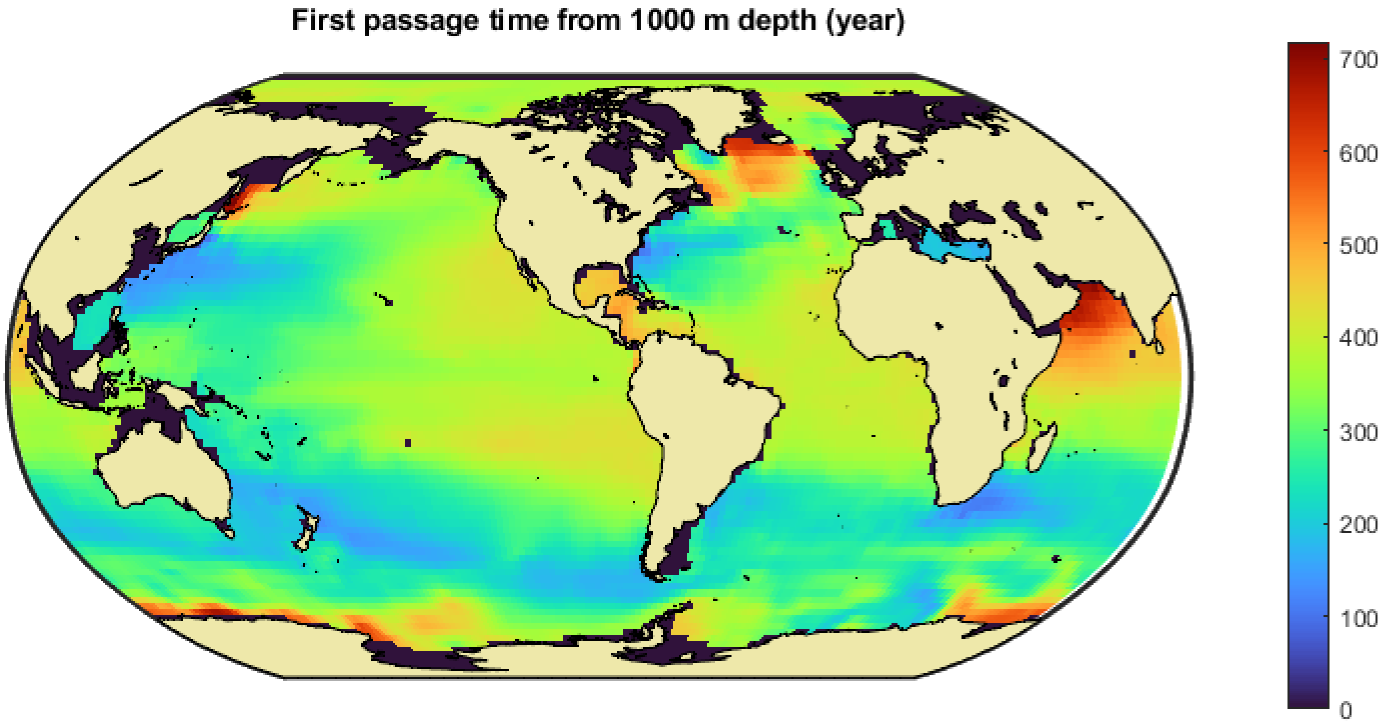
Results - Export and Sequestration

Species	Area [10^6 km^2]	Abundance [$\#/m^2$]	Biomass [GgC]	Injection [GgC / yr]	Sequestration [PgC]	Sequestration time scale [yr]	Sequestration biomass ratio [-]
C. hyperboreus	16	500 - 11,500	38 - 59	12 - 28	7.5 - 15.5	427 - 749	197 - 263
C. finmarchicus (ext.)	3.8	15,000 - 40,000	4.9 - 12	2.5 - 7.8	1.2 - 4.0	494 - 509	245 - 333
N. tonsus	6.57	5,000 - 27,000	19 - 26	17 - 24	2.7 - 7.5	157 - 311	142 - 288
C. acutus	30.7	800 - 1,300	6 - 19	4 - 14	1.5 - 6.8	346 - 510	250 - 358
C. natalis	0.69	15,000 - 127,500	1.1 - 4.4	0.3 - 1.4	0.1 - 0.7	351 - 539	91 - 159
Total		500 - 127,500	69 - 120	36 - 75	13 – 35	157 - 749	

0.5 to 1% of global export flux **10 PgC / yr**

1 to 3% of global sequestered respired carbon **1300 PgC**

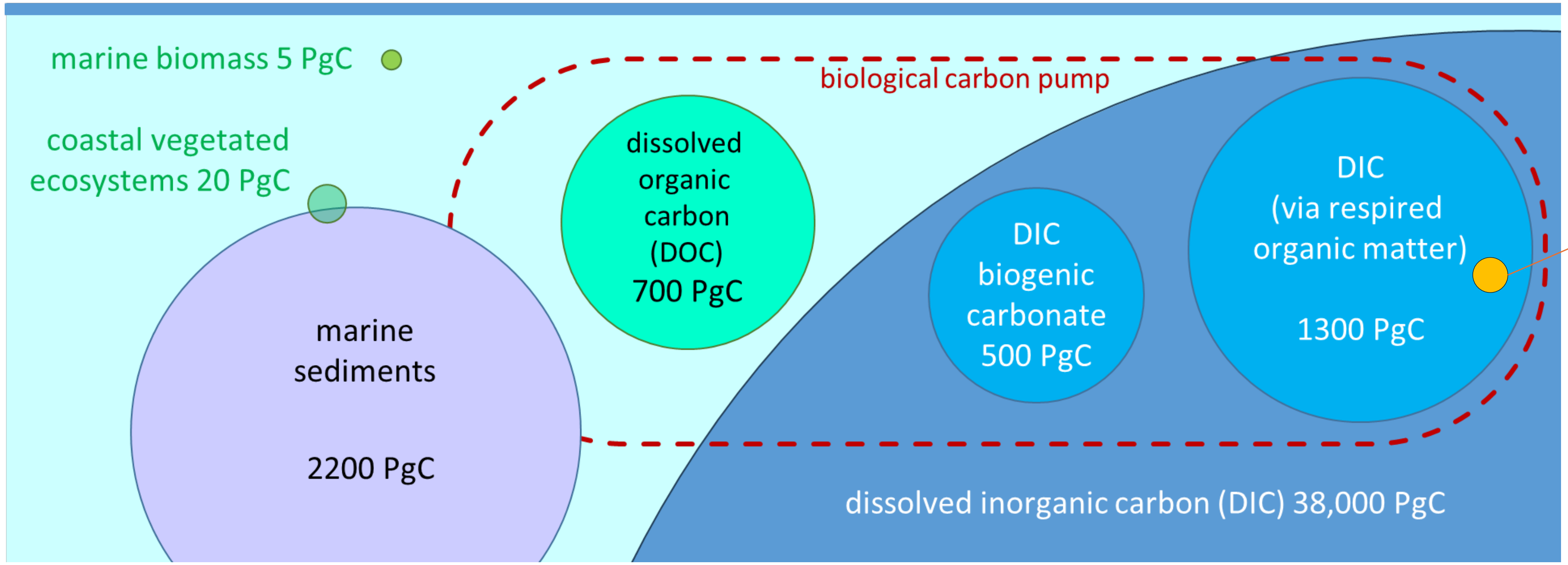
Results - Export and Sequestration



Species	Sequestration time scale [yr]
C. hyperboreus	427 - 749
C. finmarchicus (ext.)	494 - 509
N. tonsus	157 - 311
C. acutus	346 - 510
C. natalis	351 - 539
Total	157 - 749

Residence time ≈ 500 years

Results - Export and Sequestration



13 – 35 PgC

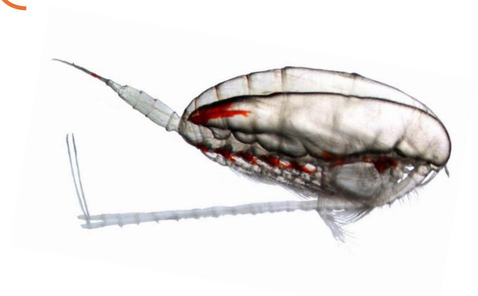
Calanus finmarchicus

Calanus hyperboreus

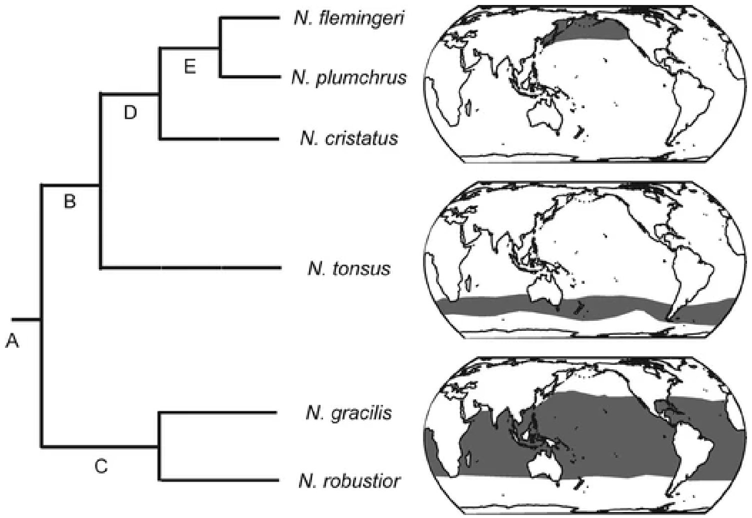
Calanoides natalis

Calanoides acutus

*Neocalanus tonsus**



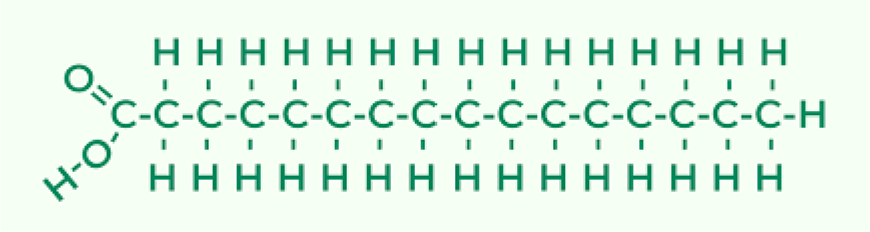
*Western Pacific sector only



Biogeography extension for

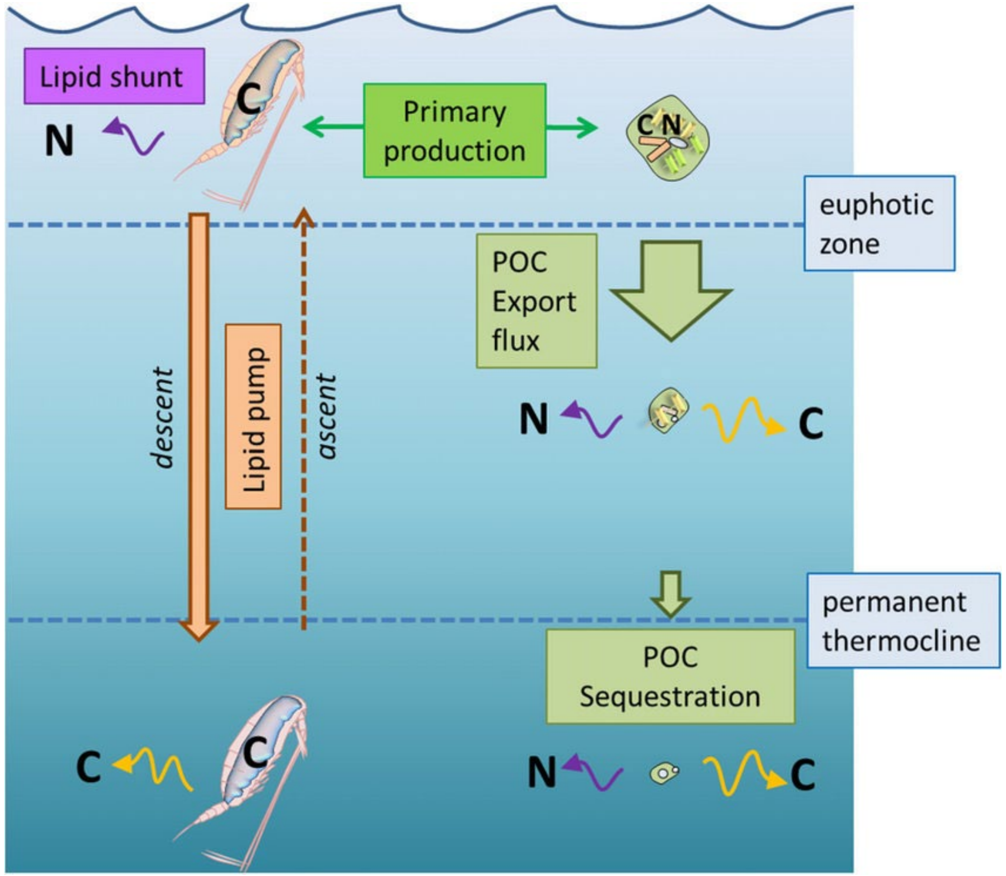
Neocalanus tonsus 23–62 PgC

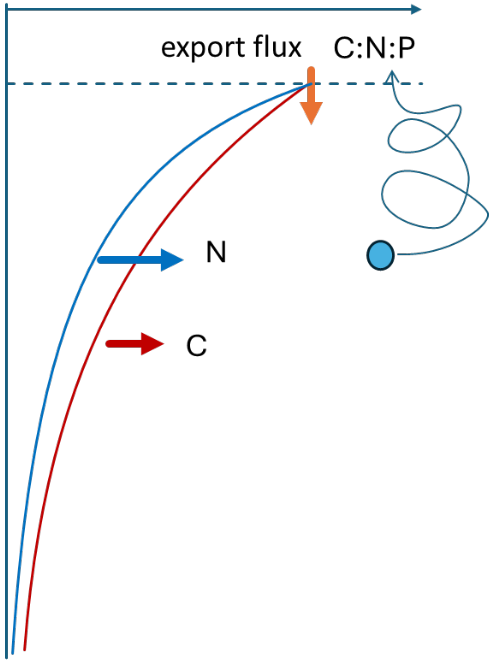
Lipid Shunt



Decoupling the export of carbon from the export of nutrients

Lipid pump highly efficient





carbon residence time

$$\int_O C dv = \int_O N dv \, \frac{1}{\gamma_{N:C}} \, \frac{T_C}{T_N}$$

ocean carbon reservoir

ocean nitrogen reservoir

Redfield

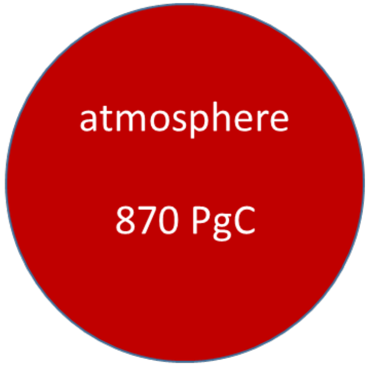
nitrogen residence time

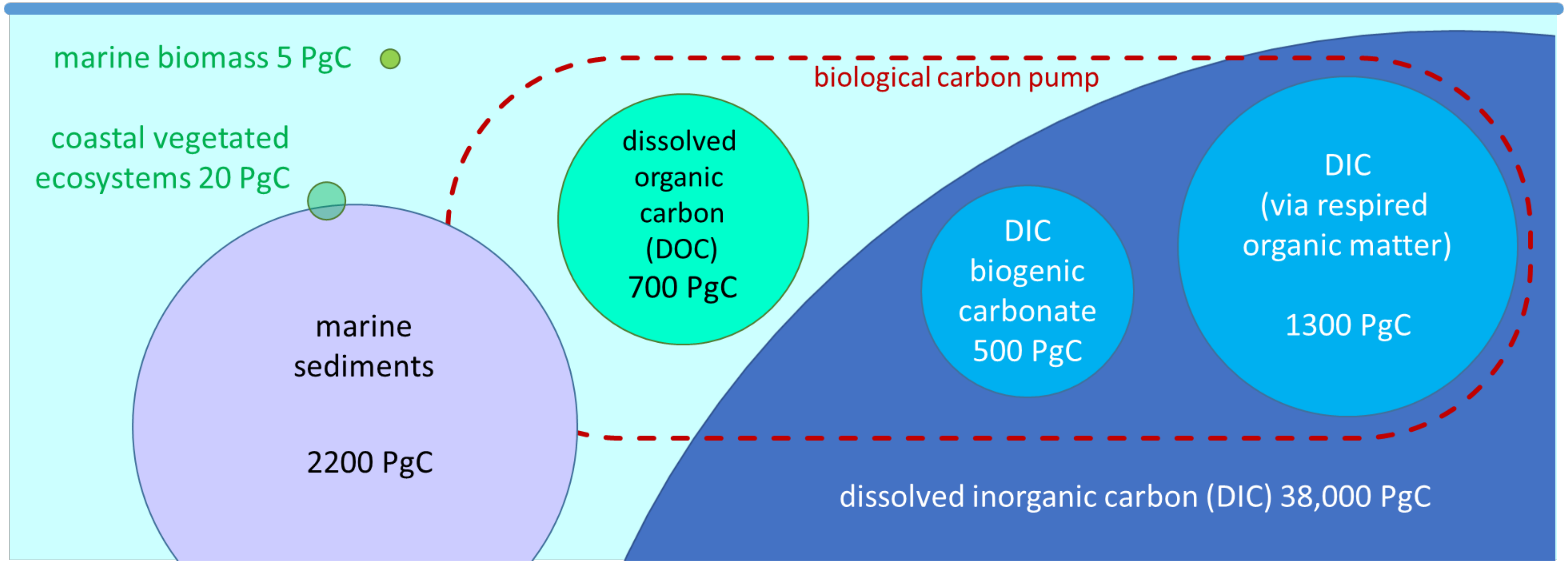
Legacy Carbon

The carbon capital of marine biota is not in their living biomass, but rather the carbon laid down by preceding generations.

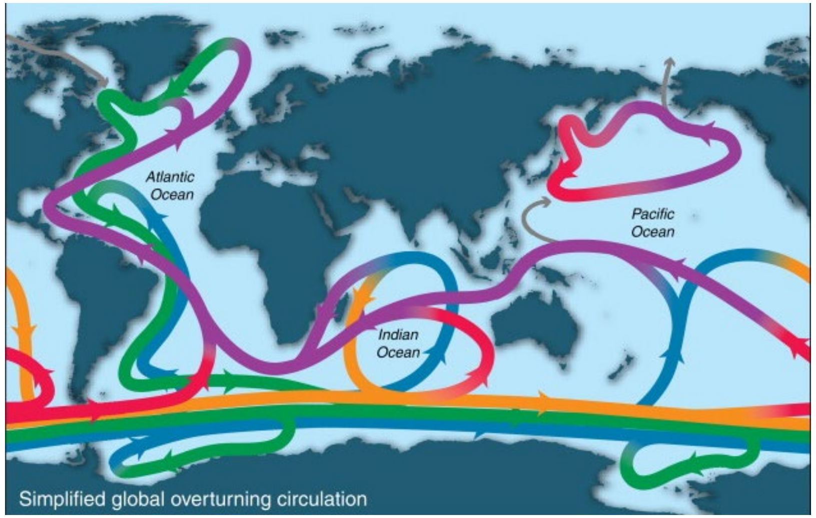
If left undisturbed, reservoirs tend to equilibrium on the time scale of their residence times.

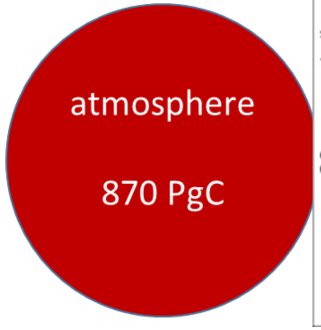
Equilibrium => flux in ≈ flux out

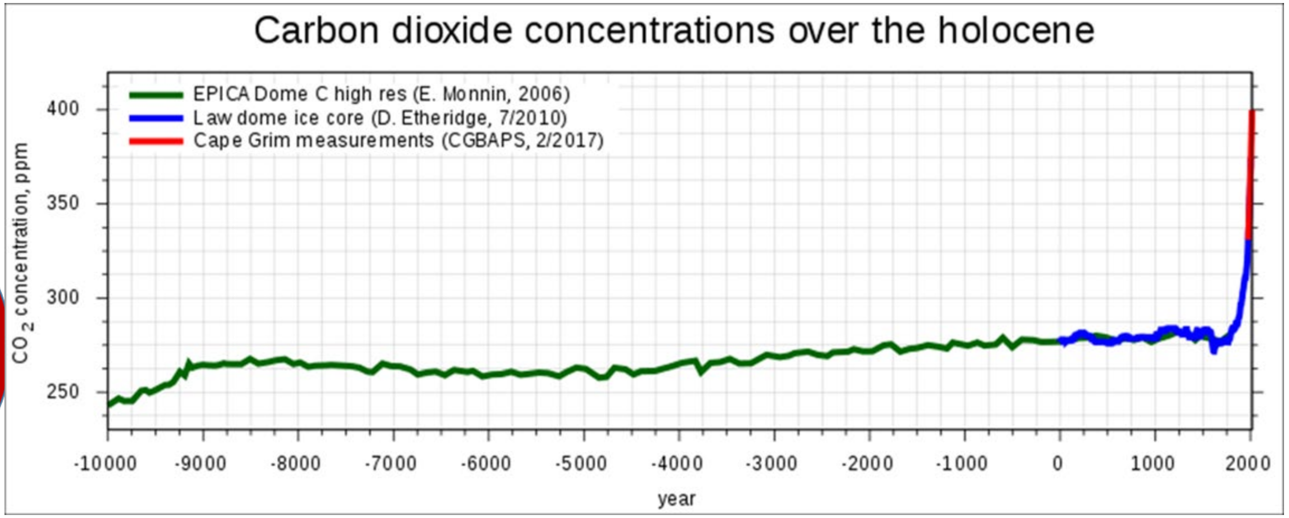


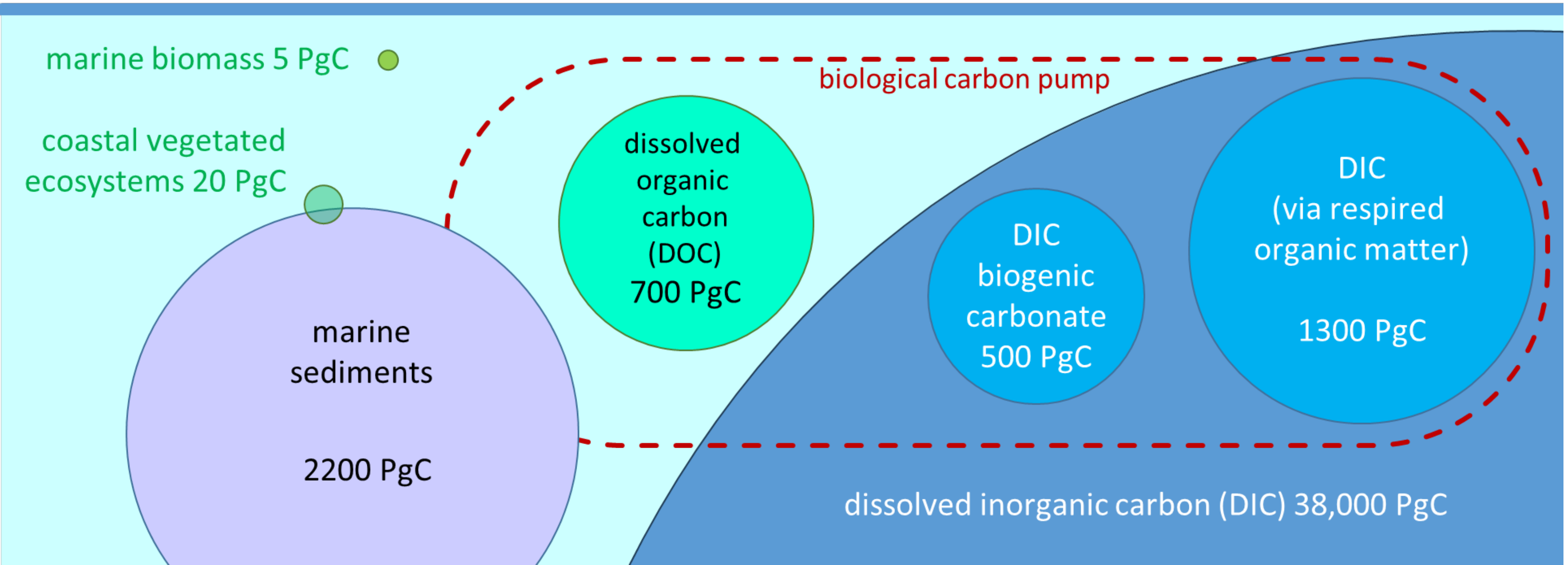


Legacy Carbon







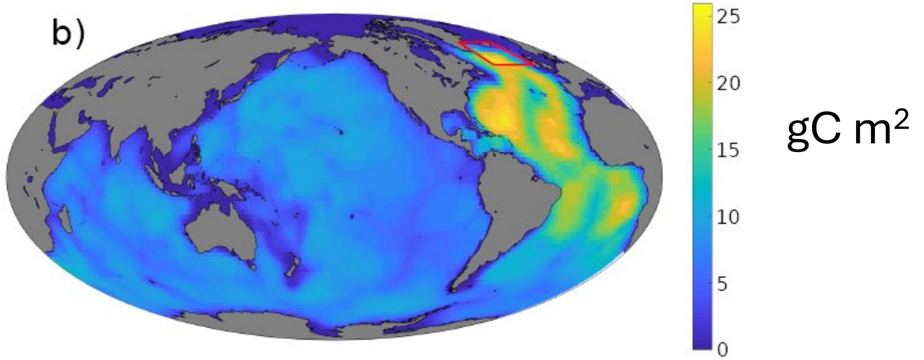


Living biomass : sequestered carbon

How much sequestered carbon is maintained in the oceans per unit living biomass for various species

Species	Biomass [GgC]	Sequestration [PgC]	Sequestration biomass ratio [-]
C. hyperboreus	38 - 59	7.5 - 15.5	240
C. finmarchicus (ext.)	4.9 - 12	1.2 - 4.0	300
N. tonsus	19 - 26	2.7 - 7.5	200
C. acutus	6 - 19	1.5 - 6.8	300
C. natalis	1.1 - 4.4	0.1 - 0.7	120
Total	69 - 120	13 – 35	

Global distribution of respired carbon from diapausing *Calanus finmarchicus* in the North Atlantic

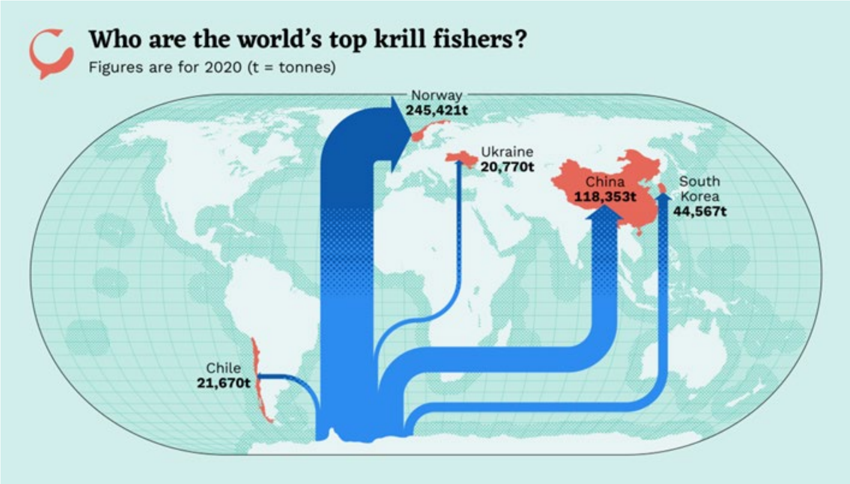


Ranking specific populations with respect to the specific sequestered carbon

Manage resource harvesting.

Fishing down the food web

the cost in Legacy Carbon



Species	Biomass [GgC]	Sequestration [PgC]	Sequestration biomass ratio [-]
C. hyperboreus	38 - 59	7.5 - 15.5	240
C. finmarchicus (ext.)	4.9 - 12	1.2 - 4.0	300
N. tonsus	19 - 26	2.7 - 7.5	200
C. acutus	6 - 19	1.5 - 6.8	300
C. natalis	1.1 - 4.4	0.1 - 0.7	120
Total	69 - 120	13 – 35	

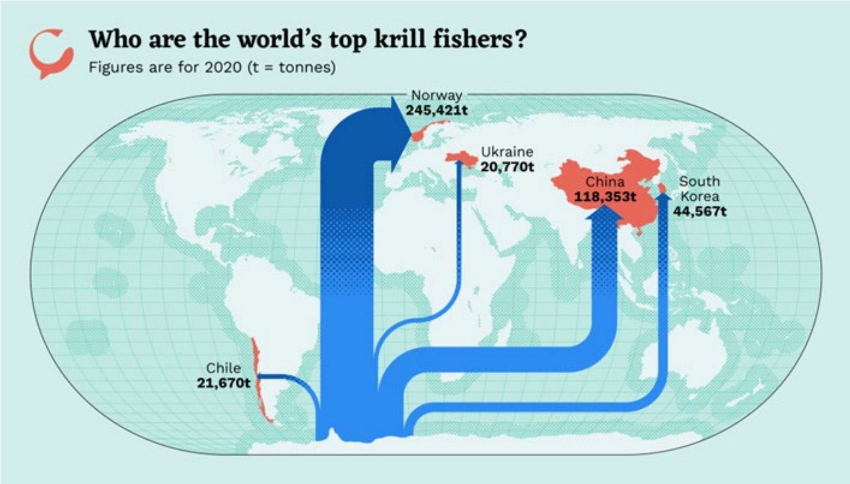
Even if fished sustainably, harvesting *Calanaus* will reduce the stock size.

A reduction is stock size by M tonnes will cause the release of 300 x M tonnes of carbon from the oceans.

Fisheries Management is not just about sustainably maintaining populations, it also has an impact on carbon sequestration that is not fully appreciated.

Fishing down the food web

the cost in Legacy Carbon



Species	Biomass [GgC]	Sequestration [PgC]	Sequestration biomass ratio [-]
C. hyperboreus	38 - 59	7.5 - 15.5	240
C. finmarchicus (ext.)	4.9 - 12	1.2 - 4.0	300
N. tonsus	19 - 26	2.7 - 7.5	200
C. acutus	6 - 19	1.5 - 6.8	300
C. natalis	1.1 - 4.4	0.1 - 0.7	120
Total	69 - 120	13 – 35	

Even if fished sustainably, harvesting *Calanaus* will reduce the stock size.

A reduction is stock size by M tonnes will cause the release of 300 x M tonnes of carbon from the oceans.

Fisheries Management is not just about sustainably maintaining populations, it also has an impact on carbon sequestration that is not fully appreciated.

Thank you