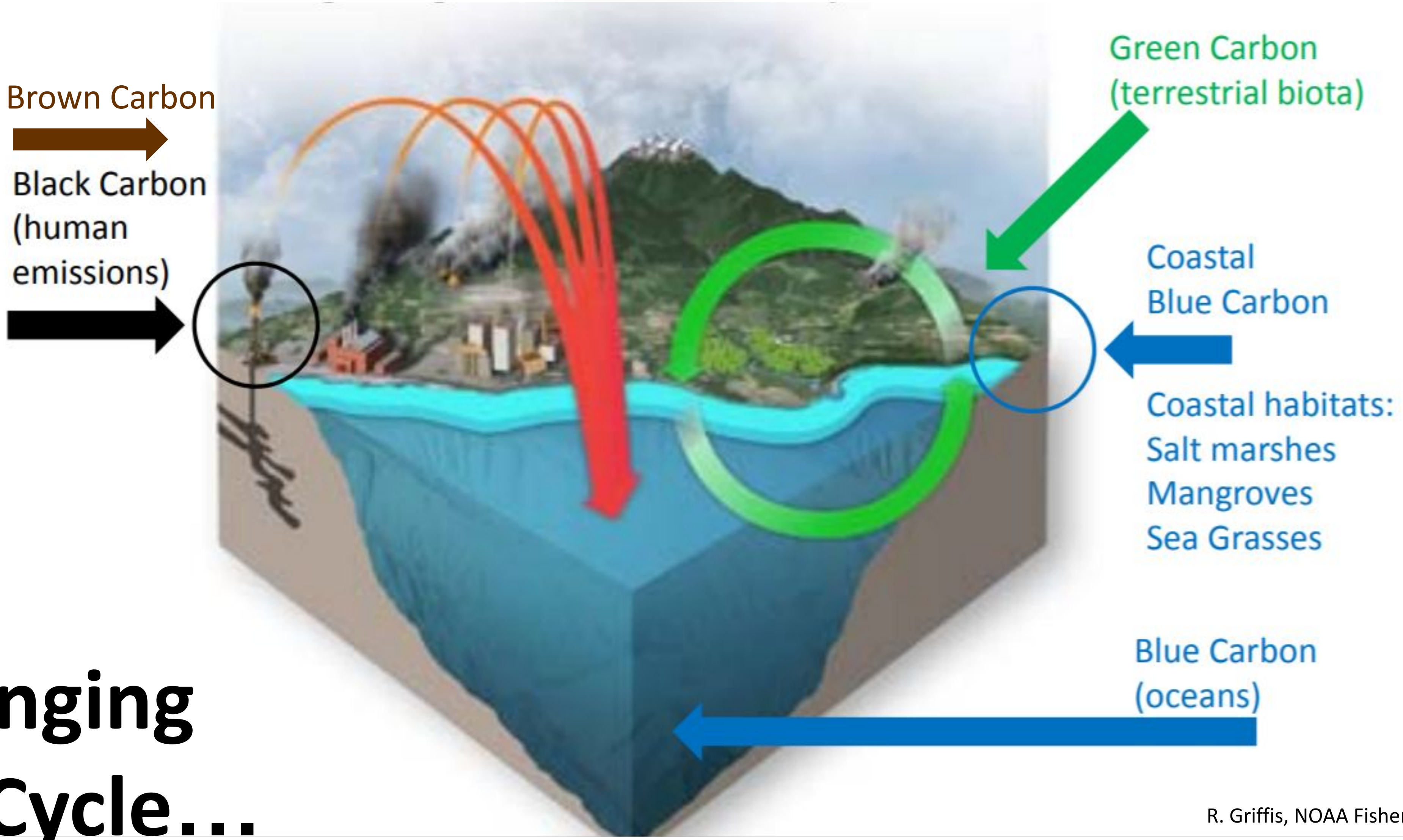
BLUE CARBON

Coastal Ecology I 2020-21
Paloma Lucena-Moya

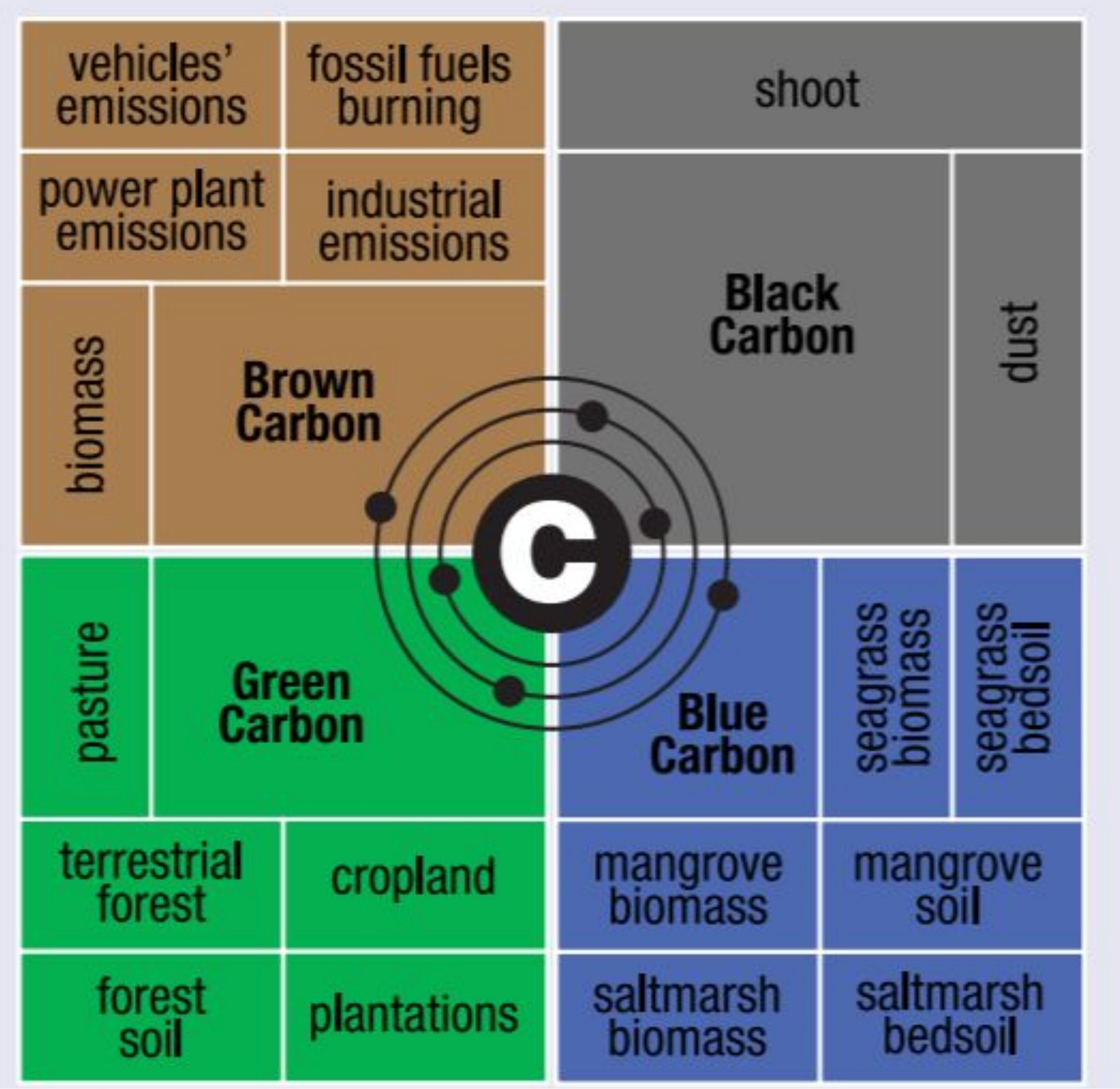
How many colours of CARBON do you know?

Carbon colours…



Our Changing Carbon Cycle…

R. Griffis, NOAA Fisheries Service, 2011



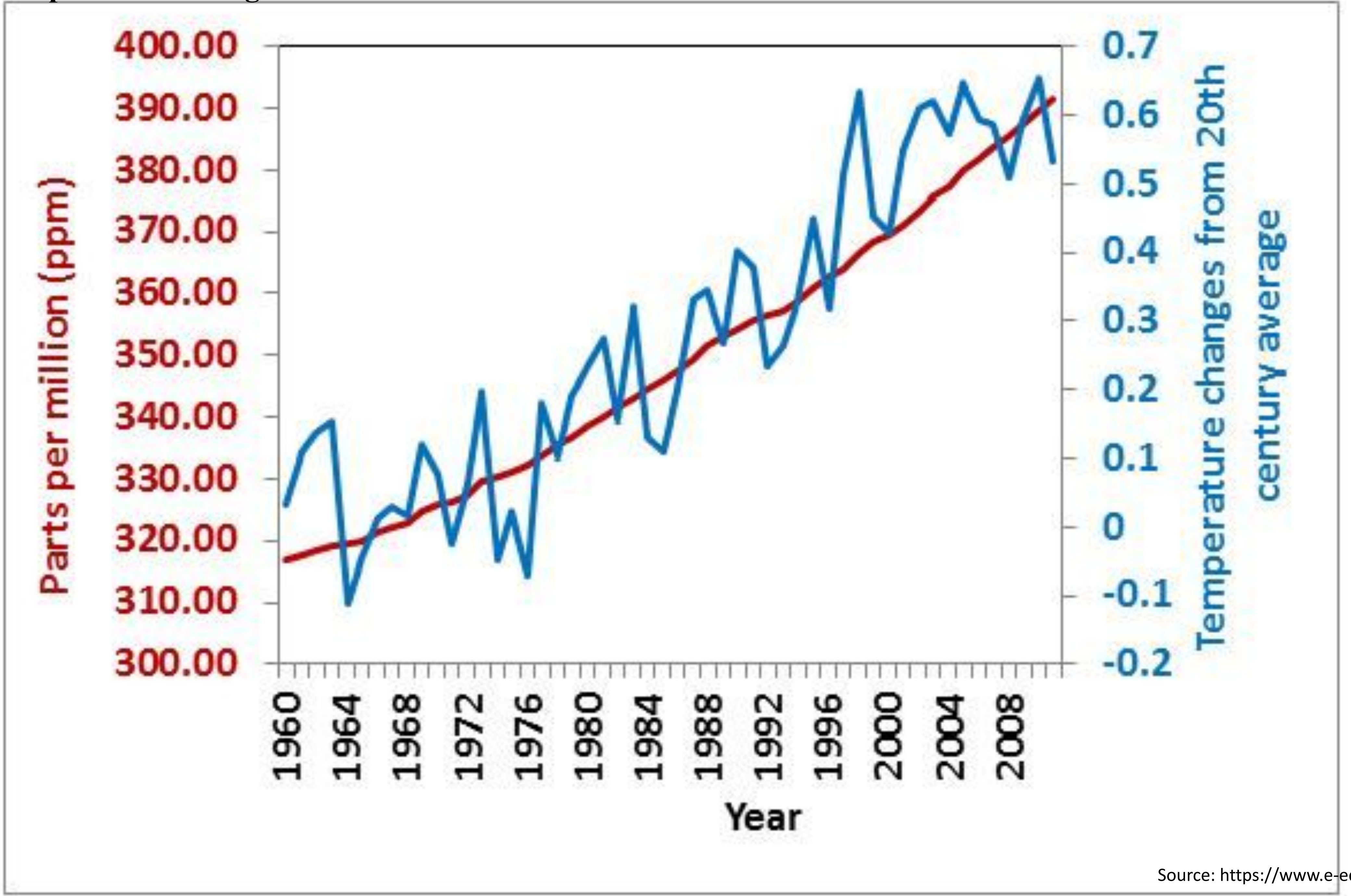
Blue carbon in the coastal ecosystems of Bangladesh (IUCN - M. Shahadat Hossain et al 2015)

What is Blue Carbon?

- ✔ Blue carbon is the carbon dioxide (CO_2) captured by the world's ocean and coastal ecosystems.
- ✔ This carbon is stored in the form of biomass and sediments (mangroves, tidal marshes, seagrass meadows, phytoplankton…)
- ✔ Blue carbon is the most effective method for long term sequestration and storage of carbon

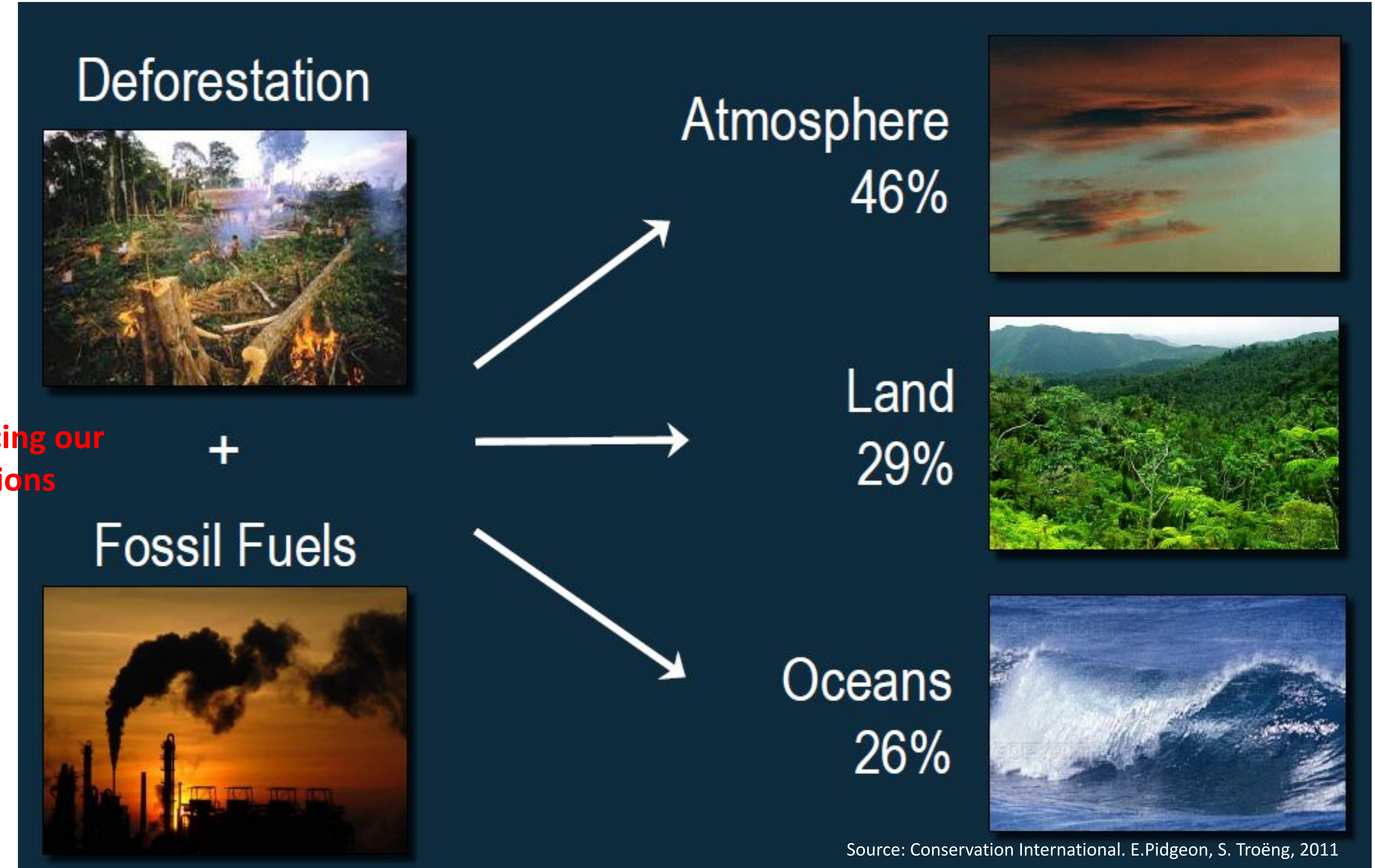
(the Ocean Foundation)

CO2 and Temperature Changes 1960-2008



Source: https://www.e-education.psu.edu

Oceans absorb greenhouse gases (GHG)

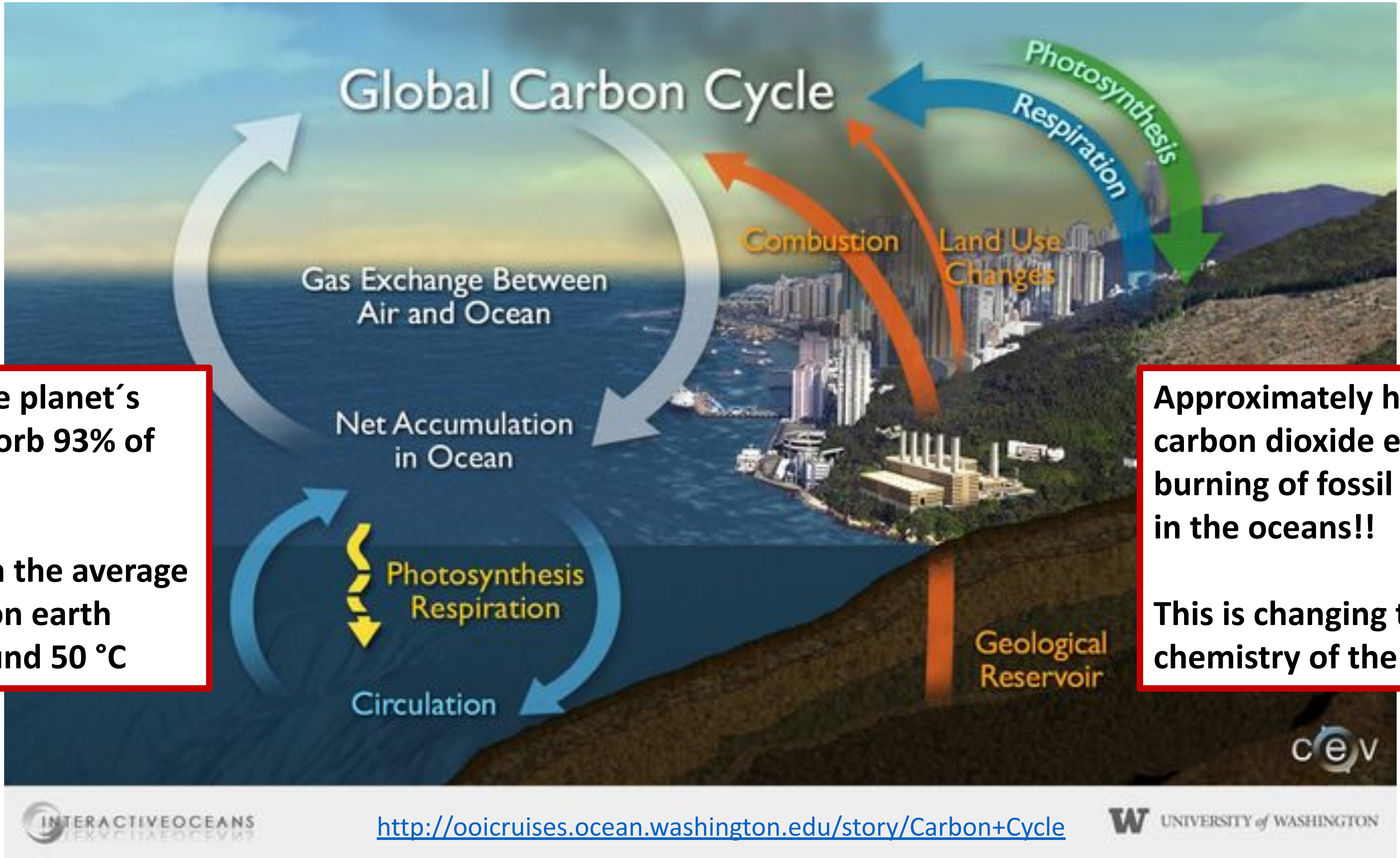


Reducing our emissions

Increasing storing capacity

Blue Carbon

Gas exchange between the atmosphere and the oceans removes carbon dioxide and sequesters some of it for long periods of time in the deep sea.



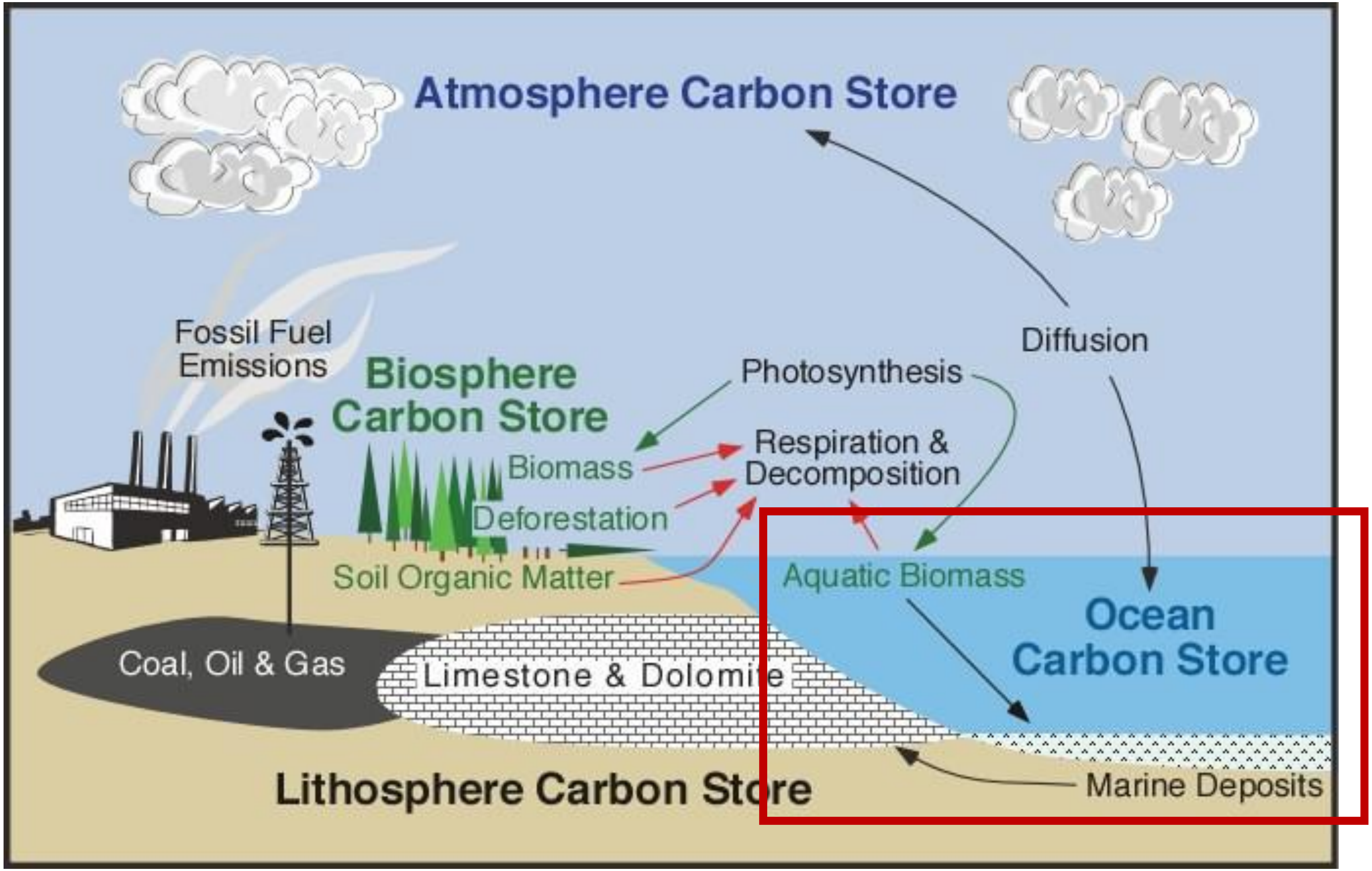
Oceans are the planet´s heat sink (absorb 93% of the heat)

With no ocean the average temperature on earth would be around 50 °C

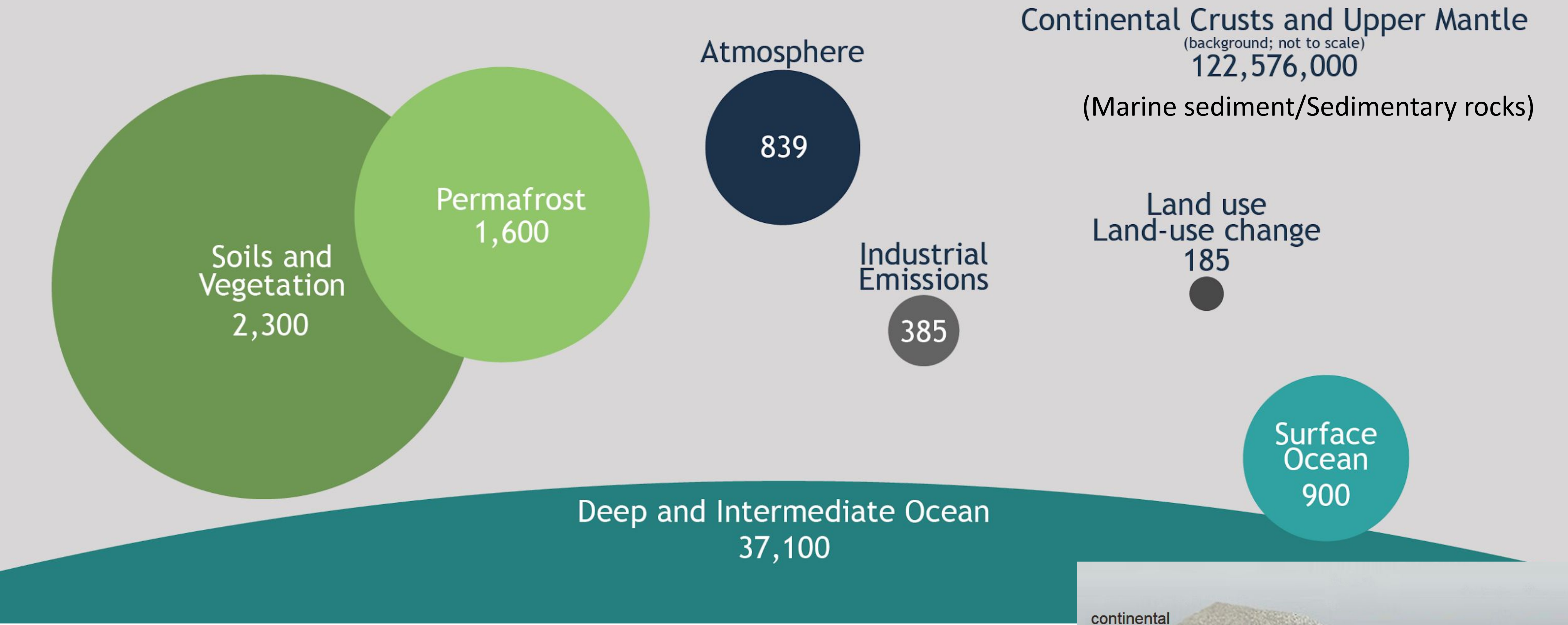
Approximately half (and 1/3) of all carbon dioxide emitted due to the burning of fossil fuels has ended up in the oceans!!

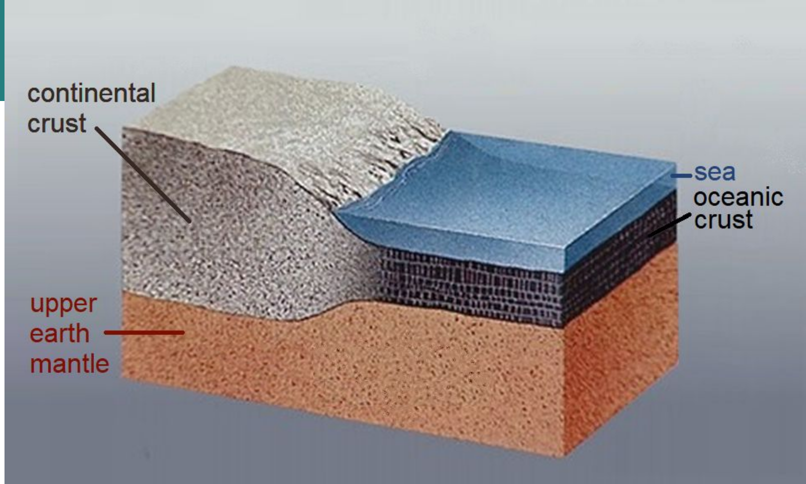
This is changing the basic chemistry of the oceans!

Without this process, CO_2 levels in the atmosphere would be much higher



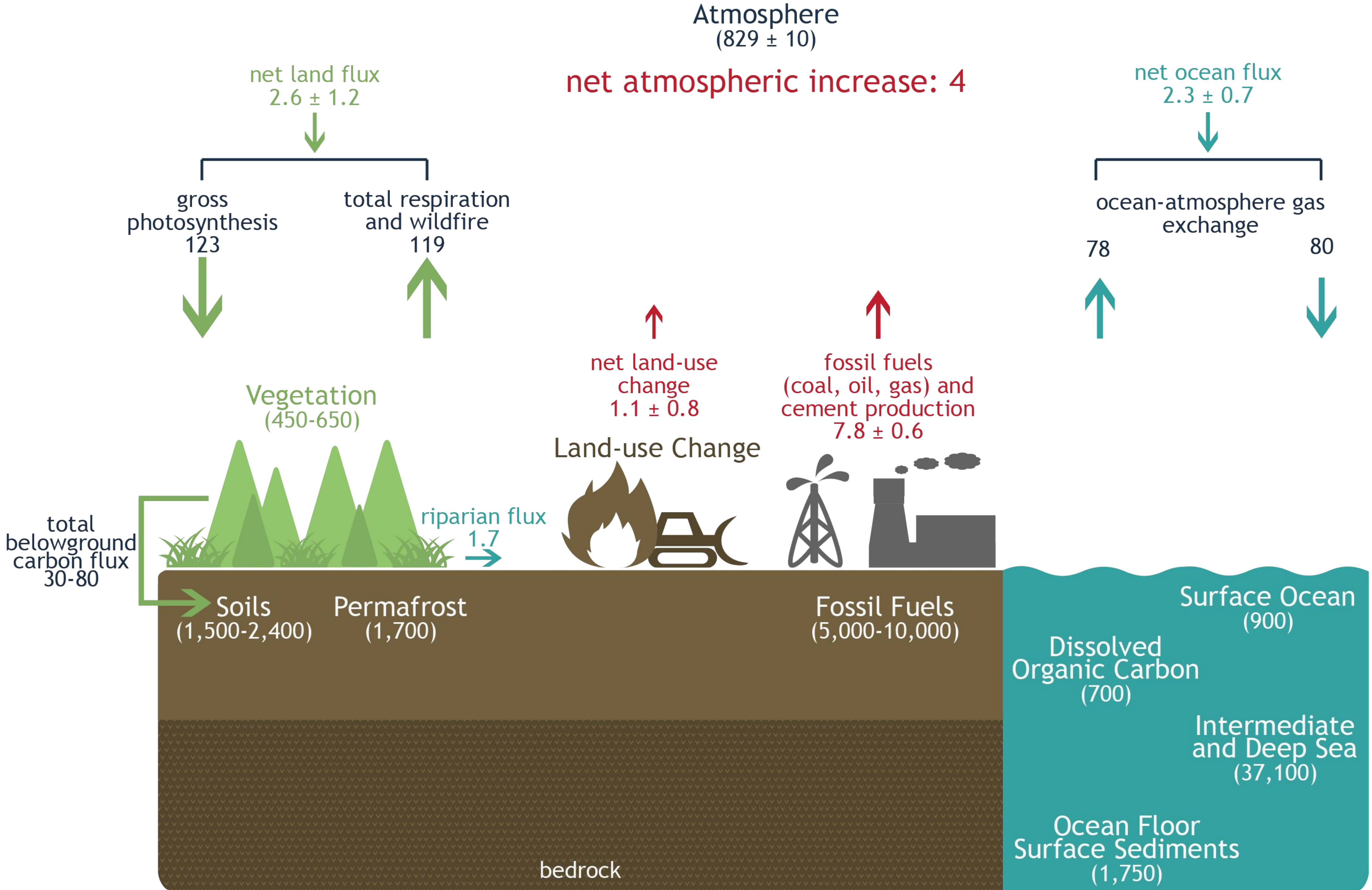
Atmosphere Carbon Store
Fossil Fuel Emissions
Biosphere Carbon Store
Photosynthesis
Diffusion
Respiration & Decomposition
Biomass
Deforestation
Soil Organic Matter
Aquatic Biomass
Ocean Carbon Store
Coal, Oil & Gas
Limestone & Dolomite
Lithosphere Carbon Store
Marine Deposits





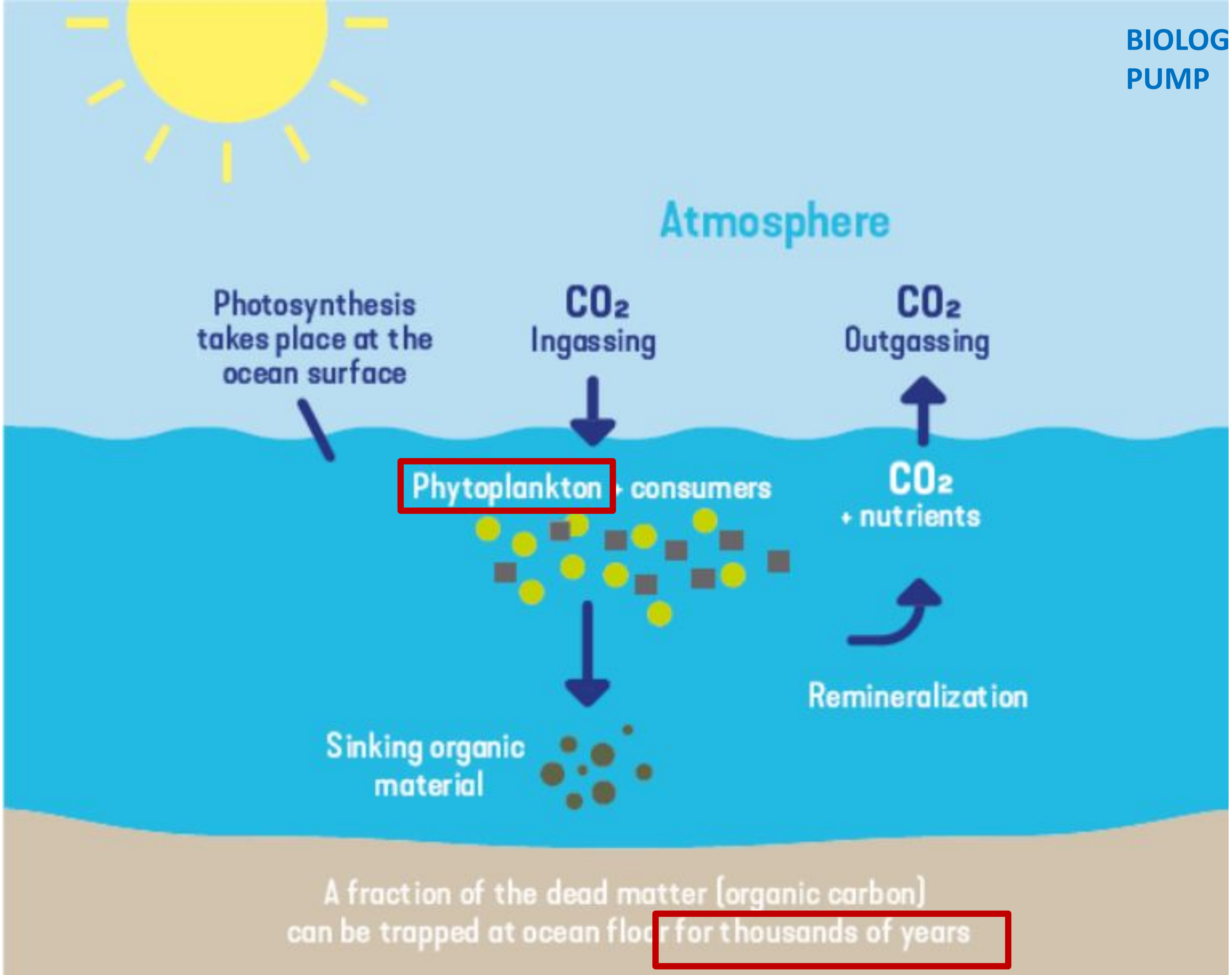
(Units: GtC gigatonnes of carbon)

https://www.fs.usda.gov/ccrc/topics/global-carbon

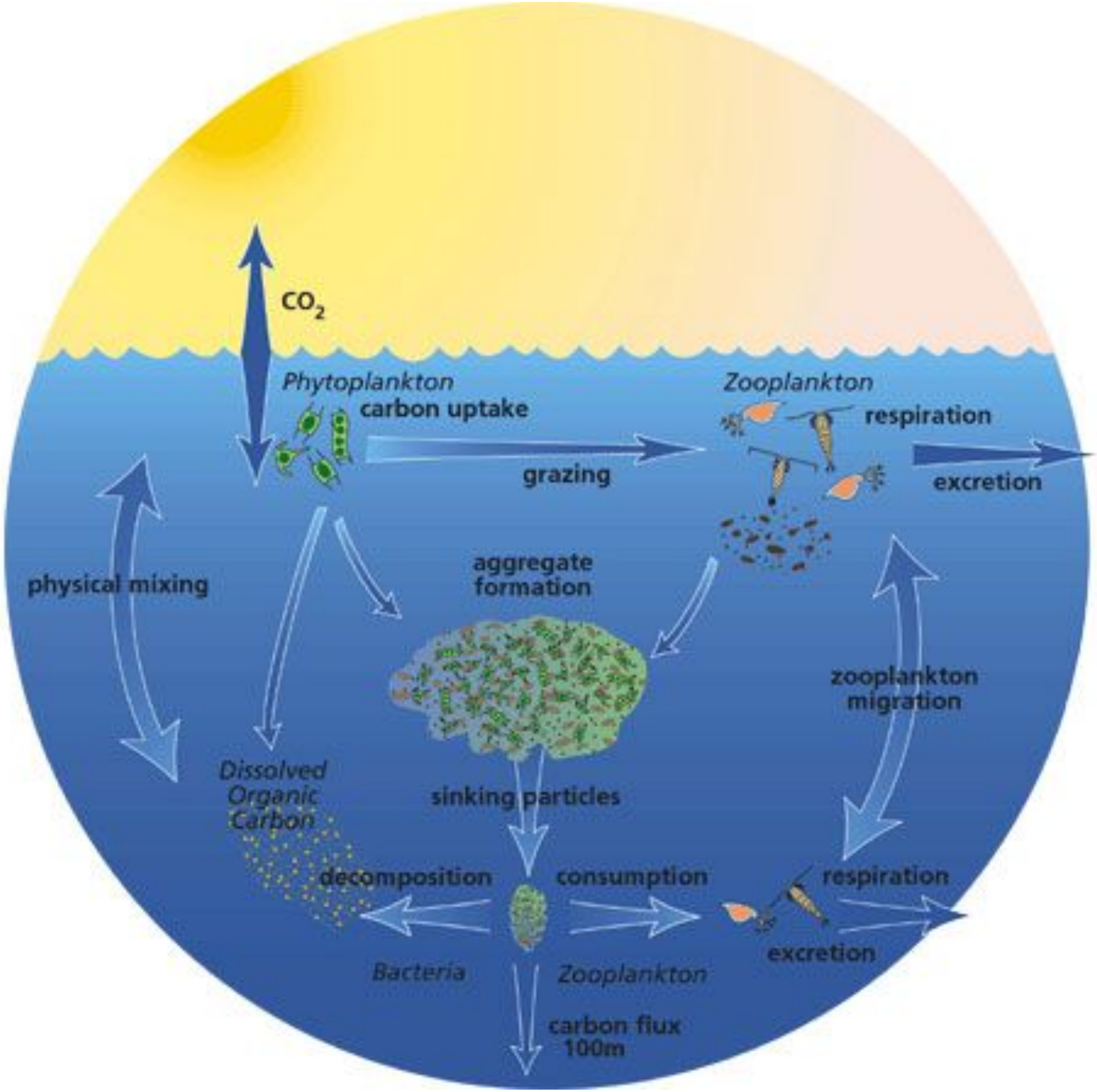


Atmosphere
(829 ± 10)
net atmospheric increase: 4
net land flux
2.6 ± 1.2
gross photosynthesis
123
total respiration and wildfire
119
net ocean flux
2.3 ± 0.7
ocean-atmosphere gas exchange
78
80
net land-use change
1.1 ± 0.8
fossil fuels (coal, oil, gas) and cement production
7.8 ± 0.6
Vegetation
(450-650)
Land-use Change
total belowground carbon flux
30-80
riparian flux
1.7
Soils
(1,500-2,400)
Permafrost
(1,700)
Fossil Fuels
(5,000-10,000)
Surface Ocean
(900)
Dissolved Organic Carbon
(700)
Intermediate and Deep Sea
(37,100)
Ocean Floor Surface Sediments
(1,750)
bedrock

BIOLOGICAL CARBON PUMP

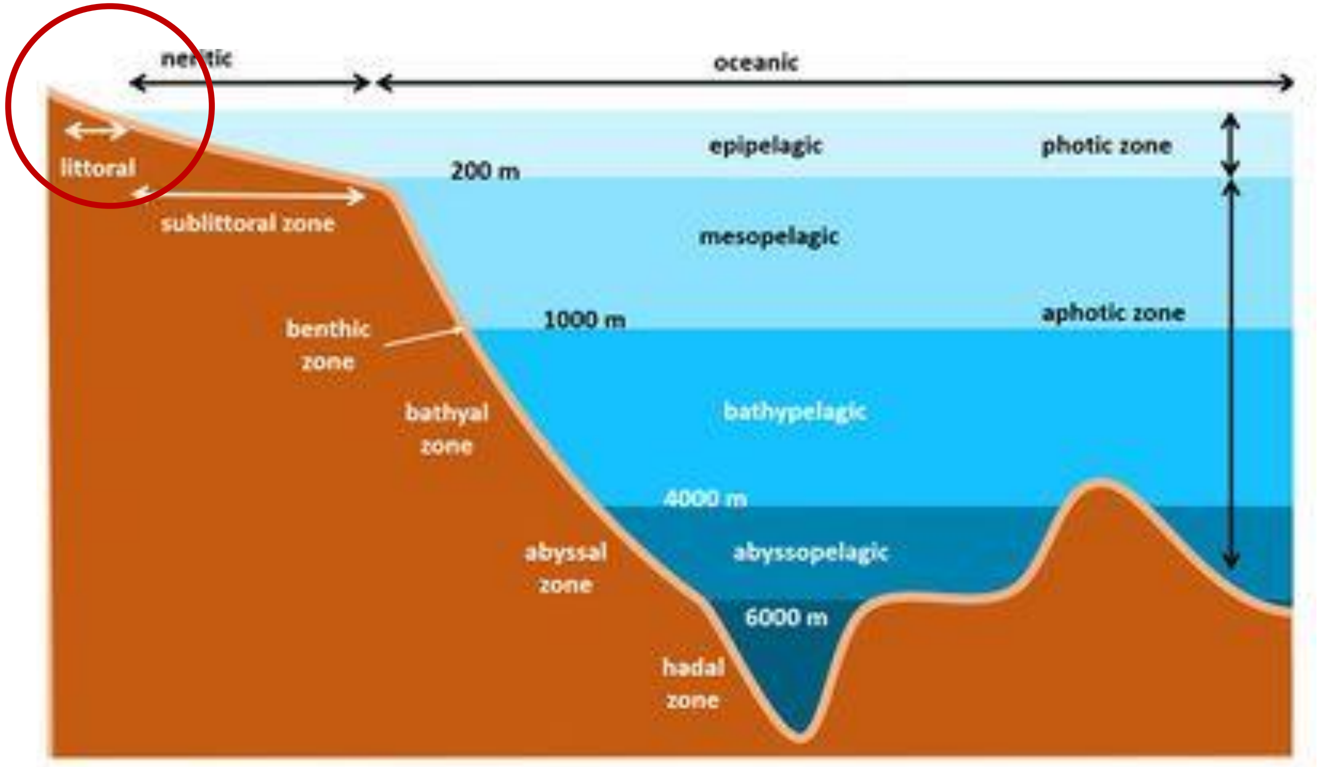


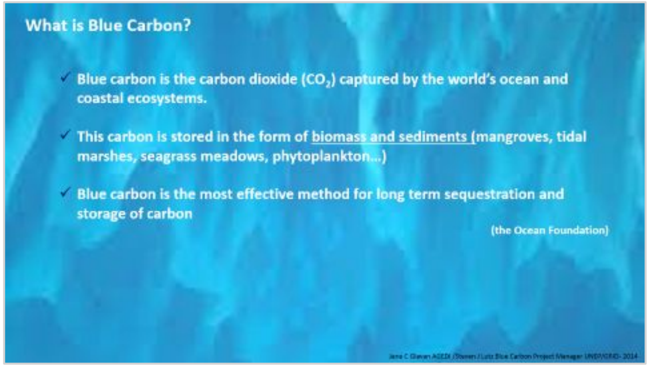
BIOLOGICAL CARBON PUMP

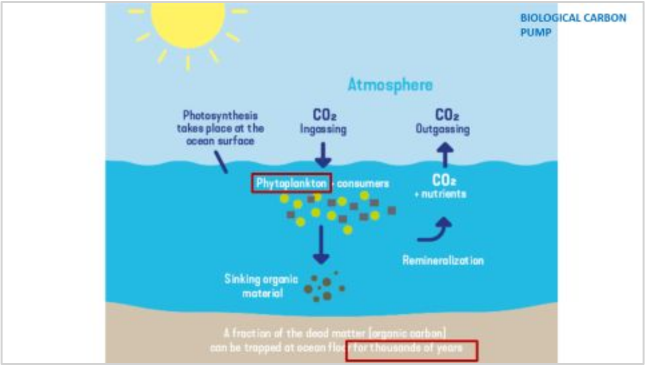


Blue carbon is the carbon dioxide (CO_2) captured by the world's ocean (deep sea) and <u>coastal ecosystems*</u>

***A coastal ecosystem is an area where land and (salty) water come together** (Lecture 2)







Coastal ecosystems transfer carbon from the atmosphere and ocean into sediments

Three key ecosystems…

Mangroves

Daintree N.P. Queensland. Claire Howell

Salt Marshes

Cumberland Island Salt Marsh in Georgia (Trish Hartmann)

Seagrass

HELCOM. Anu Suono

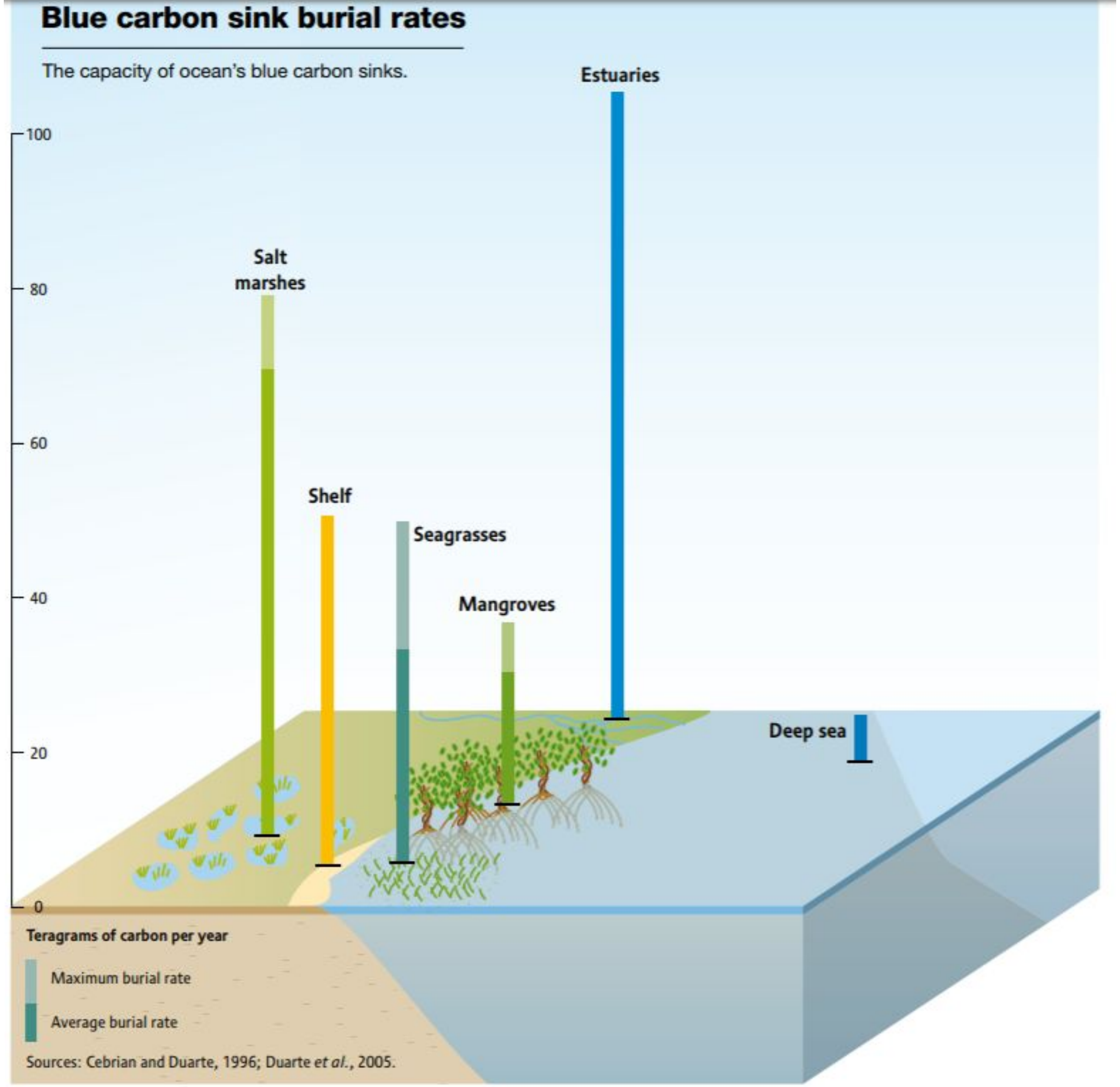
< 0.5% of seabed

capture and store majority of all carbon in ocean sediments

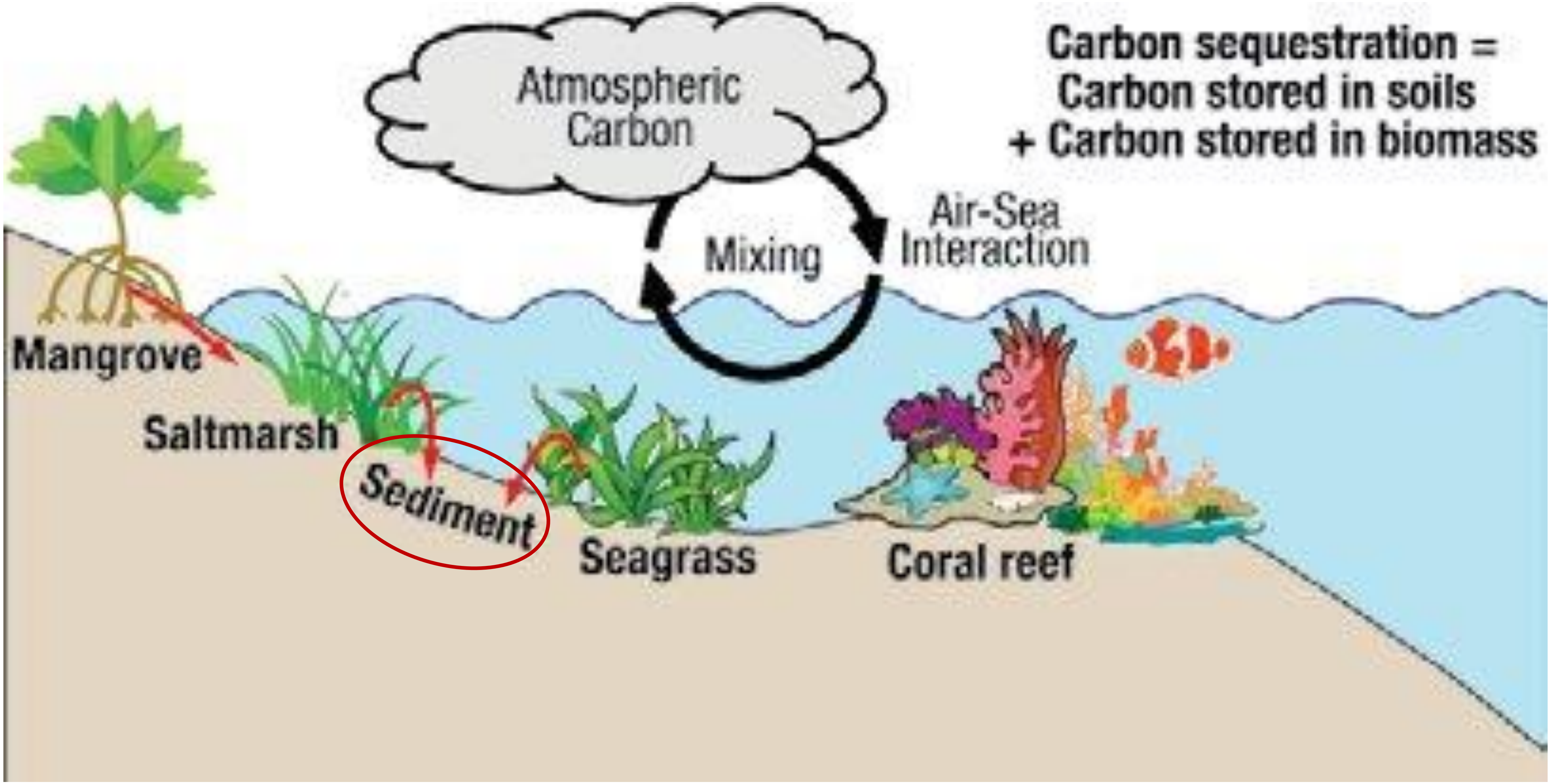
BLUE FOREST

https://www.unenvironment.org/news-and-stories/story/blue-forests-finding-coastal-and-marine-solutions-meet-paris-agreement

"TWO MINUTES ON OCEANS" (video youtube) (focused on mangroves but extrapolated to other marine ecosystems)

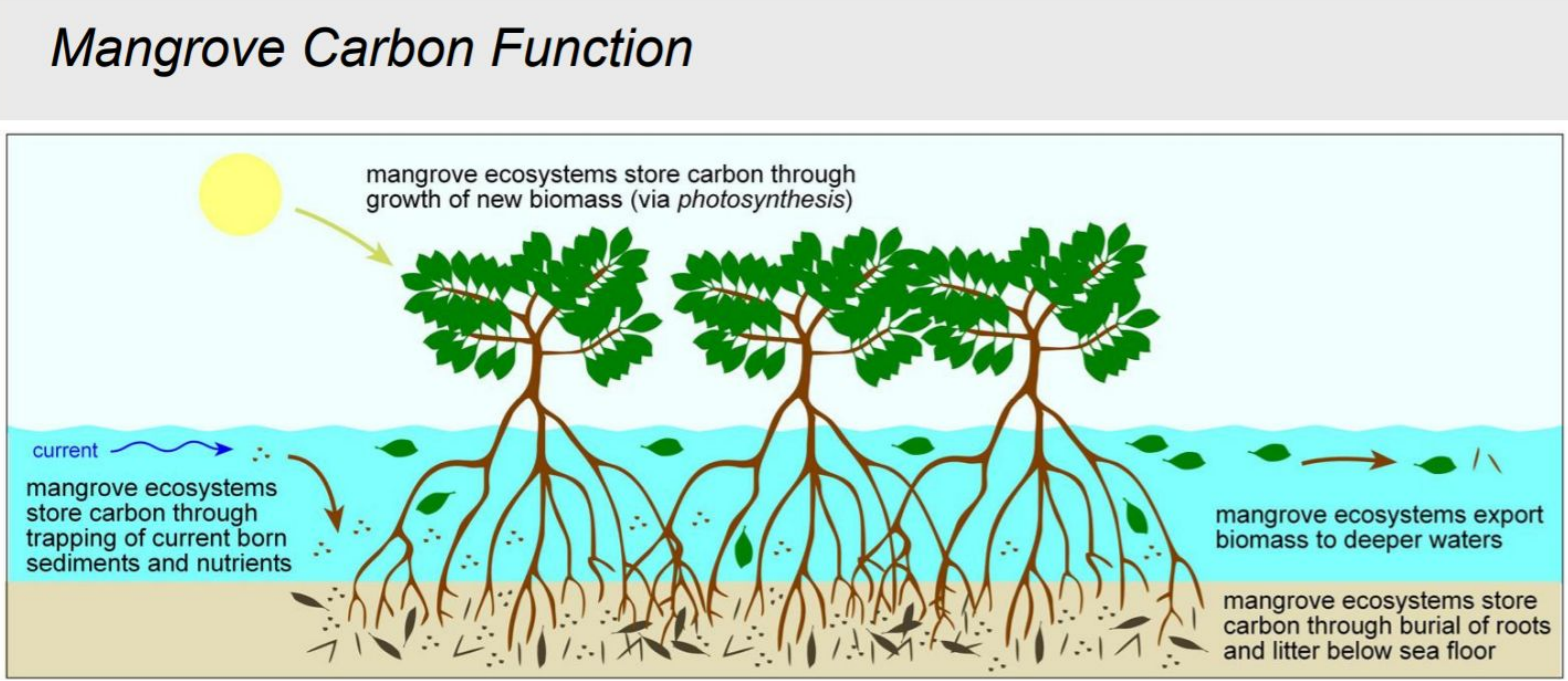


Blue carbon sink burial rates
The capacity of ocean's blue carbon sinks.
Estuaries
100
Salt marshes
80
60
Shelf
Seagrasses
40
Mangroves
Deep sea
20
0
Teragrams of carbon per year
Maximum burial rate
Average burial rate
Sources: Cebrian and Duarte, 1996; Duarte *et al.*, 2005.



Blue carbon in the coastal ecosystems of Bangladesh (IUCN - M. Shahadat Hossain et al 2015)

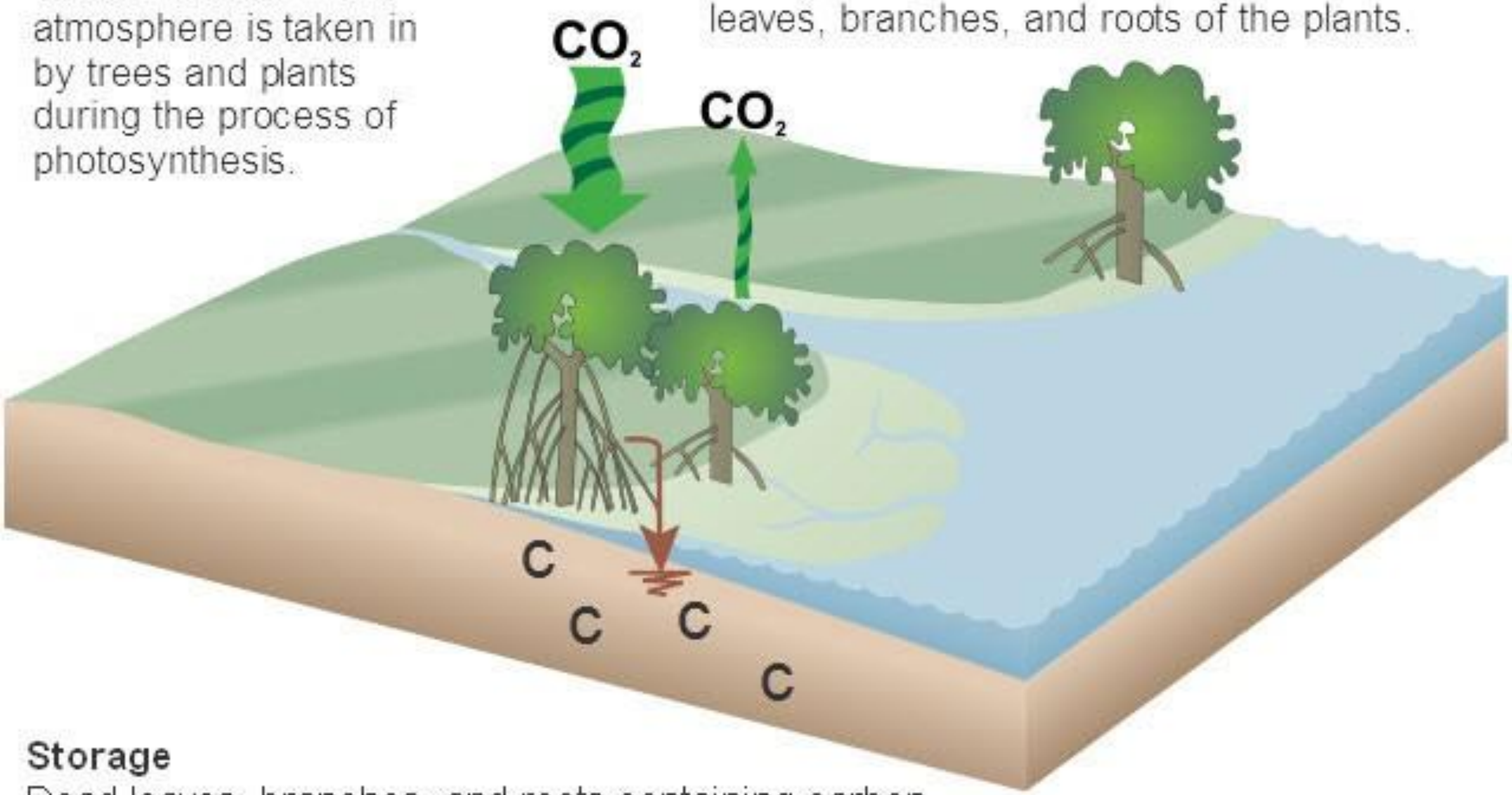
How does Blue Carbon work?



Jane C Glavan AGEDI /Steven J Lutz Blue Carbon Project Manager UNEP/GRID- 2014

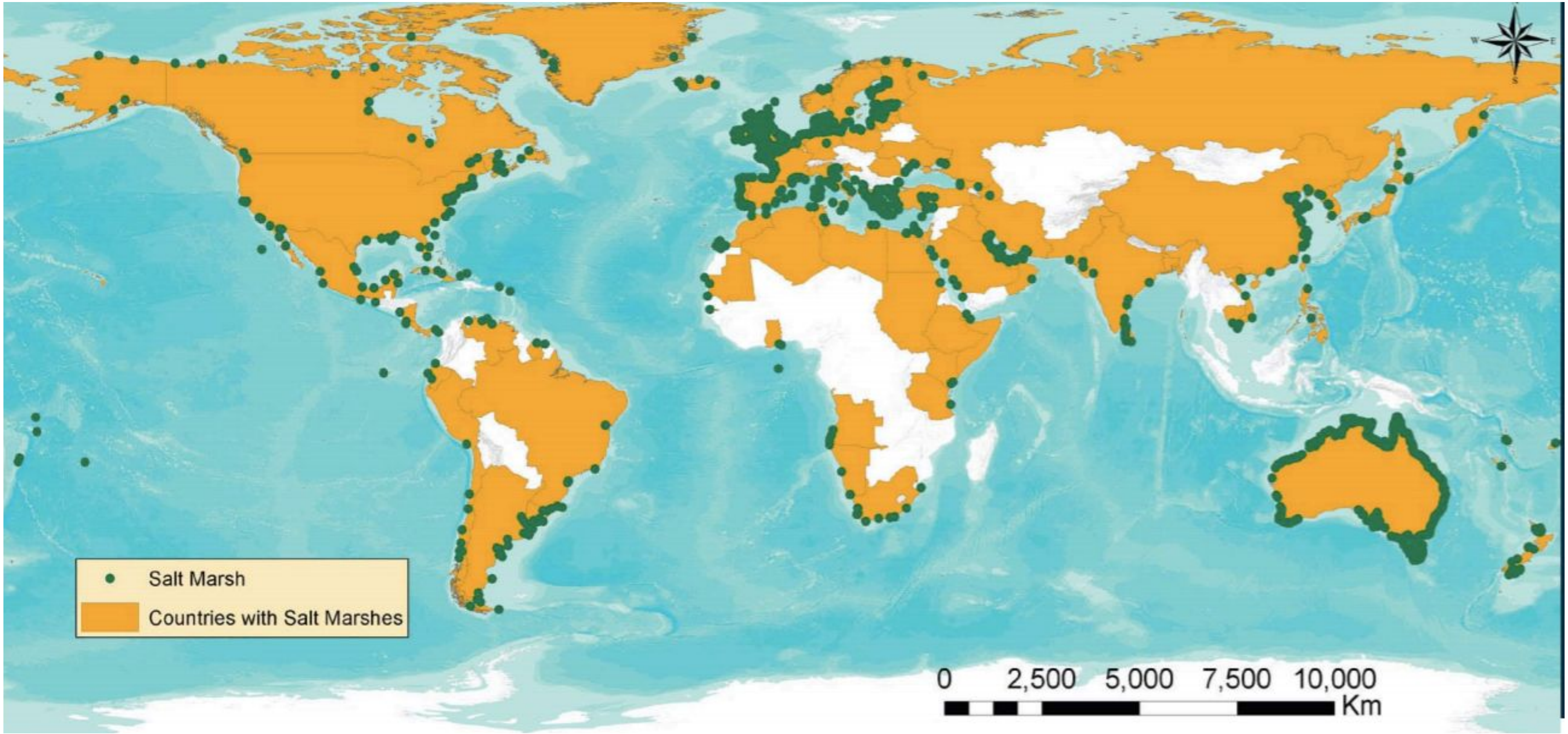
Sequestration
Carbon dioxide in the atmosphere is taken in by trees and plants during the process of photosynthesis.

Some carbon is lost back to the atmosphere through respiration. The rest is stored in the leaves, branches, and roots of the plants.



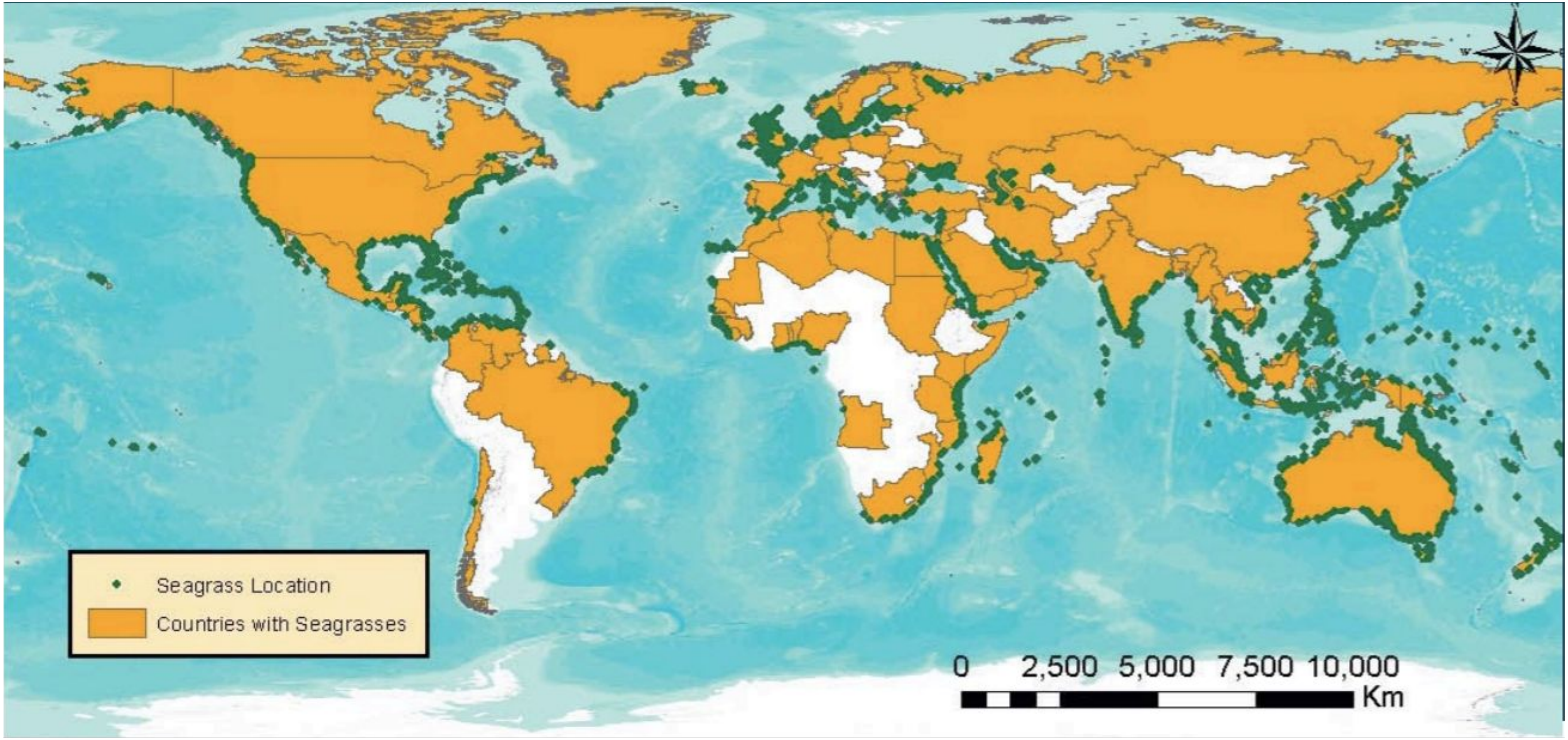
Storage
Dead leaves, branches, and roots containing carbon are buried in the soil, which is frequently, if not always, covered with tidal waters. This oxygen-poor environment causes very slow break down of the plant materials, resulting in significant carbon storage.

Global Distribution of Tidal Marshes



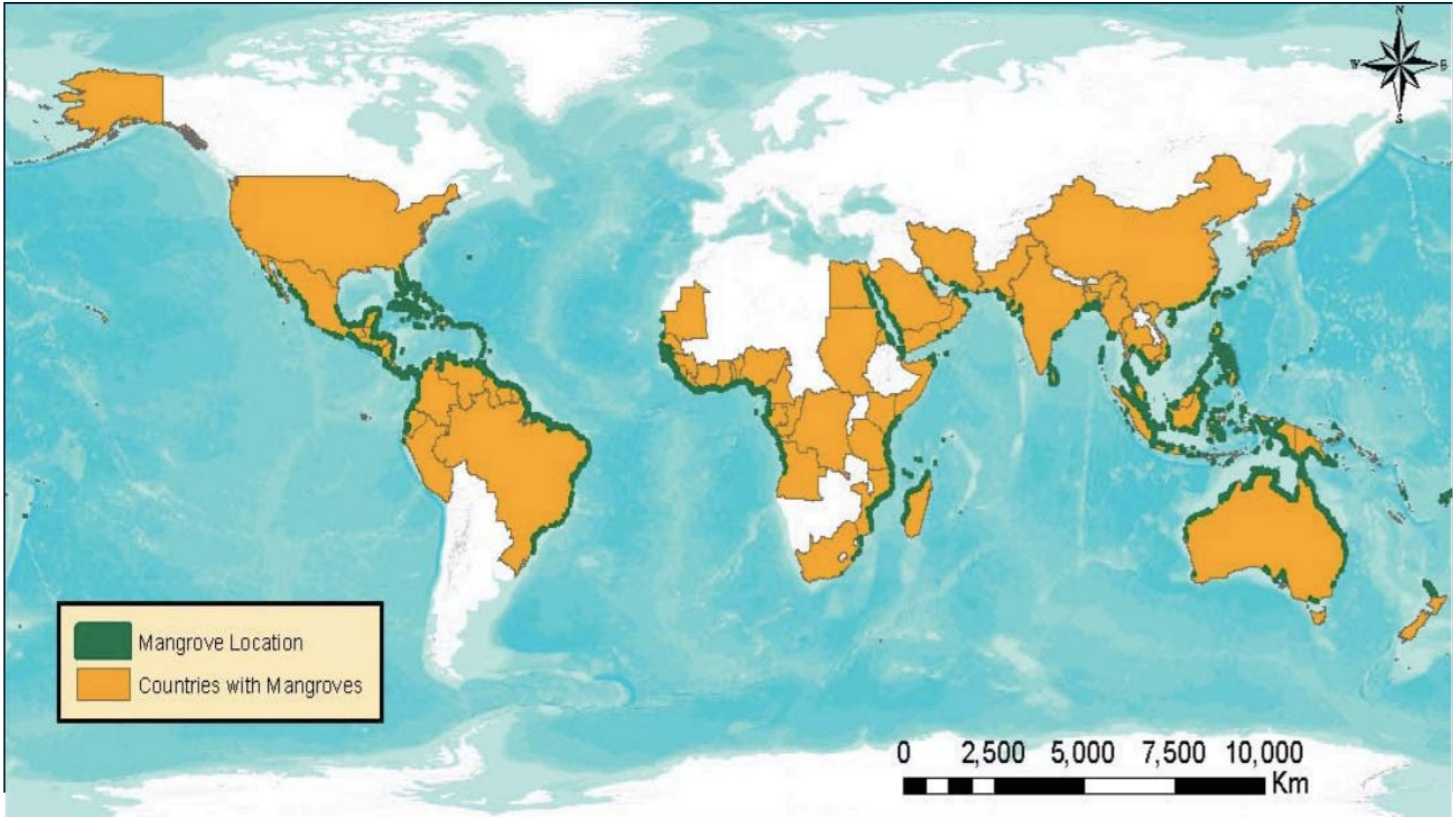
From Murray et al (2011) with UNEP-WCMC data

Global Distribution of Seagrasses



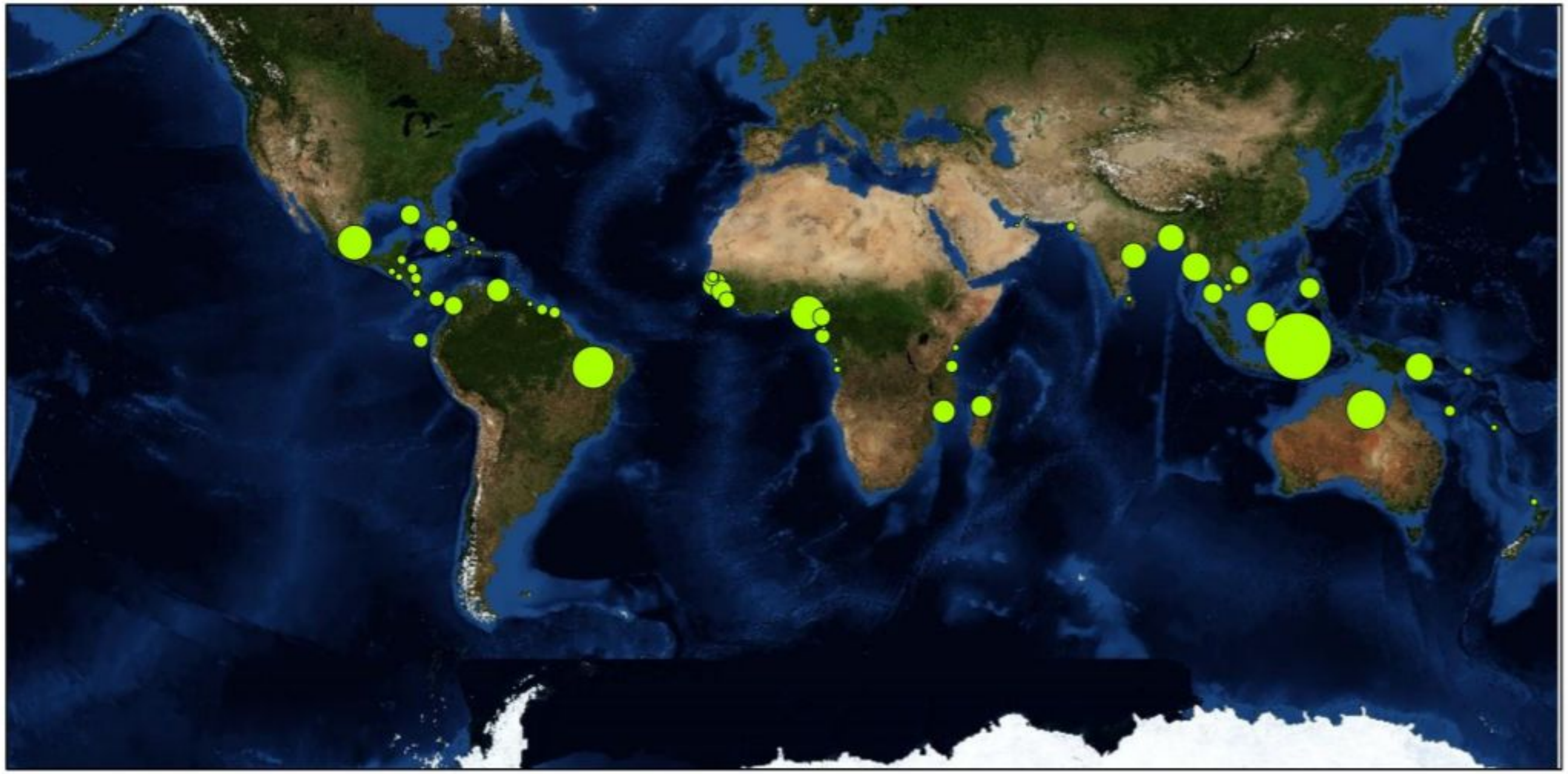
From Murray et al (2011) with UNEP-WCMC data

Global Distribution of Mangroves



From Murray et al (2011) with UNEP-WCMC data

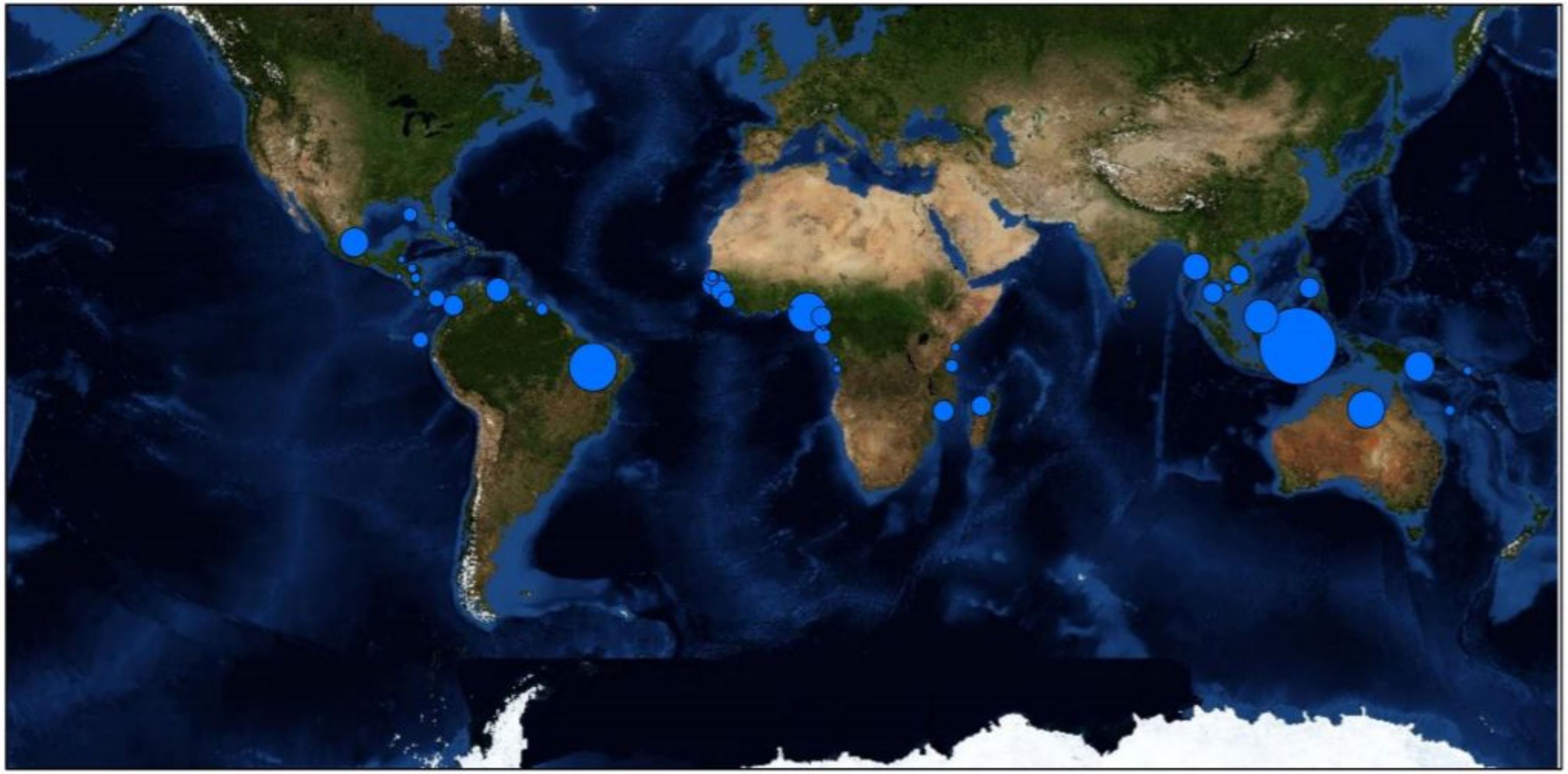
Mangroves, Global Distribution (% share of total)



Map drawn in ArcGIS using data from Giri, C. et al;. (2011), Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography, 20: 154–159.

J. Siikamäki (RFF), S. Jardine and J. Sanchirico (UC Davis), D. McLaughlin and D. Morris (RFF). RFF Briefing, New York, 2011

Carbon Storage (% share of total)



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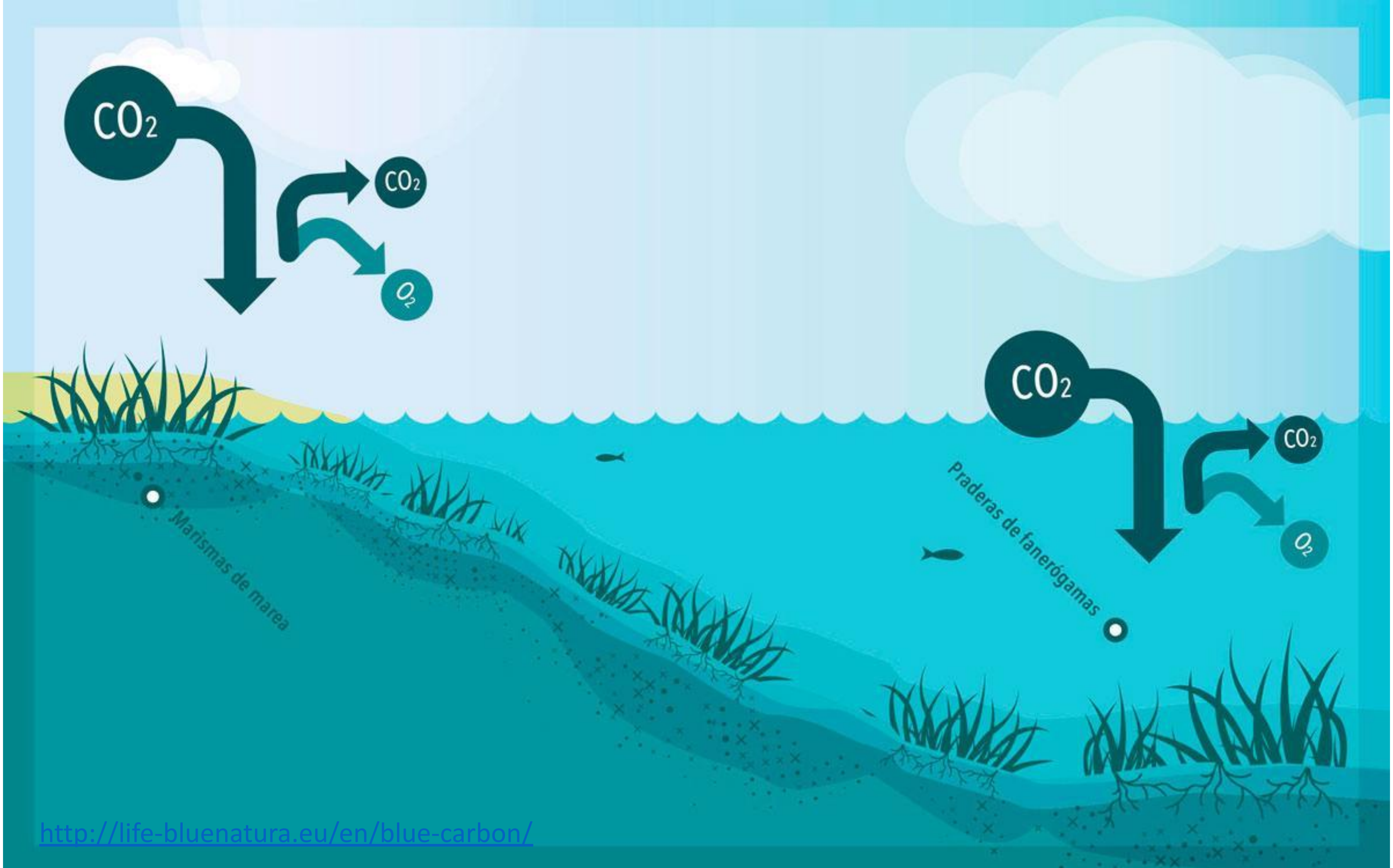
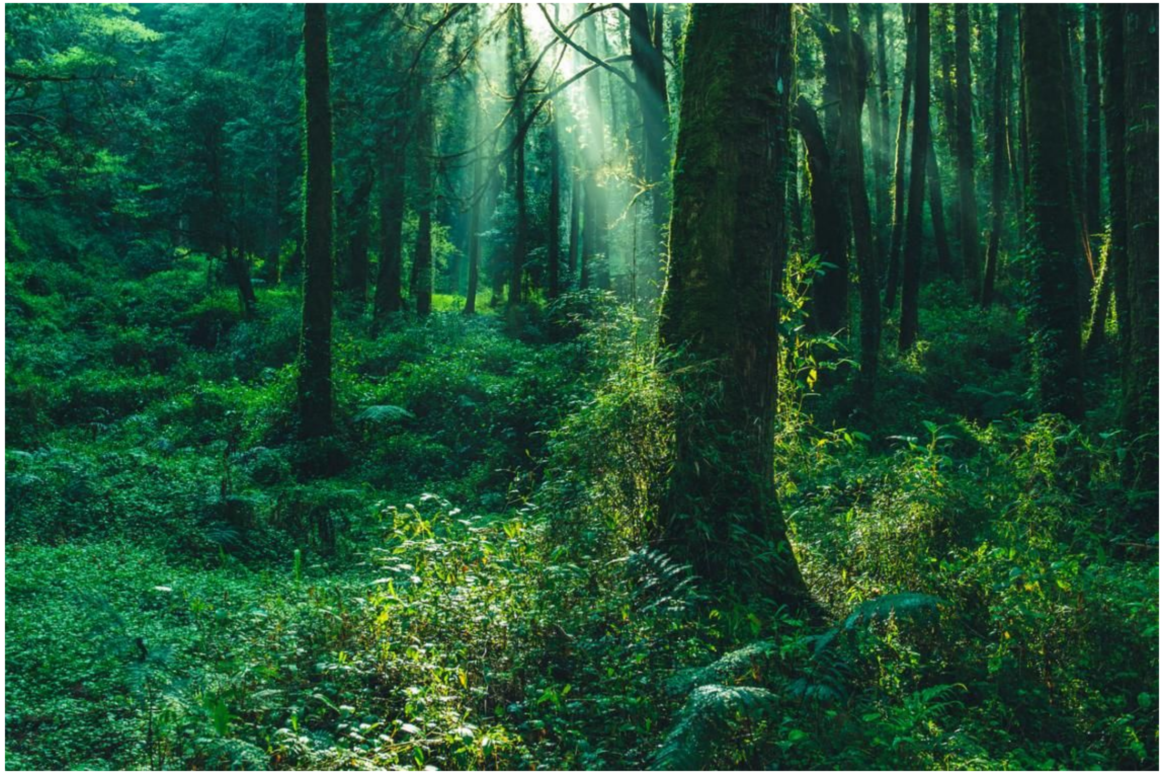


http://life-bluenatura.eu/en/blue-carbon/

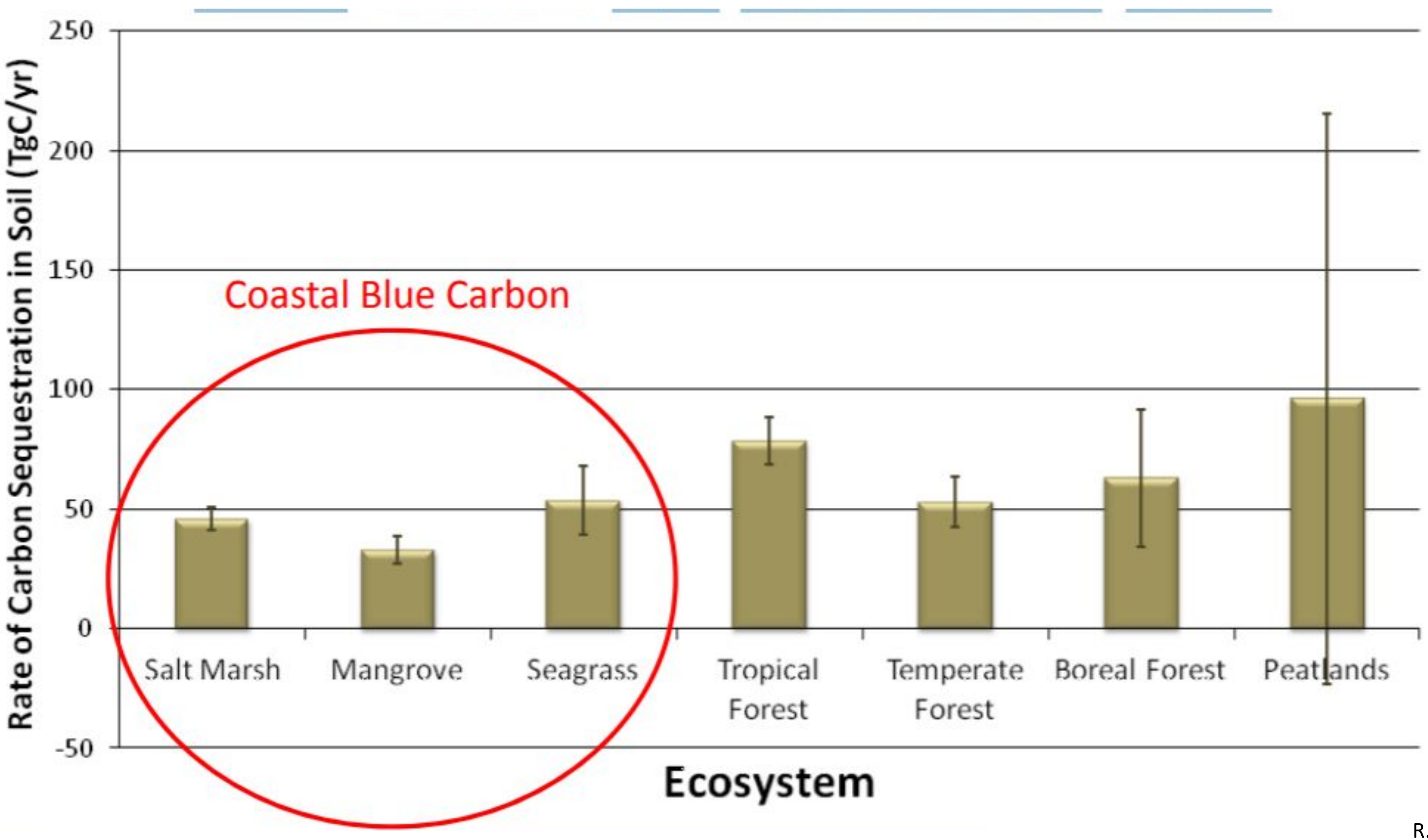
Traditionally, terrestrial ecosystems have been thought as a big carbon sink. However…



Coastal ecosystems are smaller, but the rate of sequestration are larger

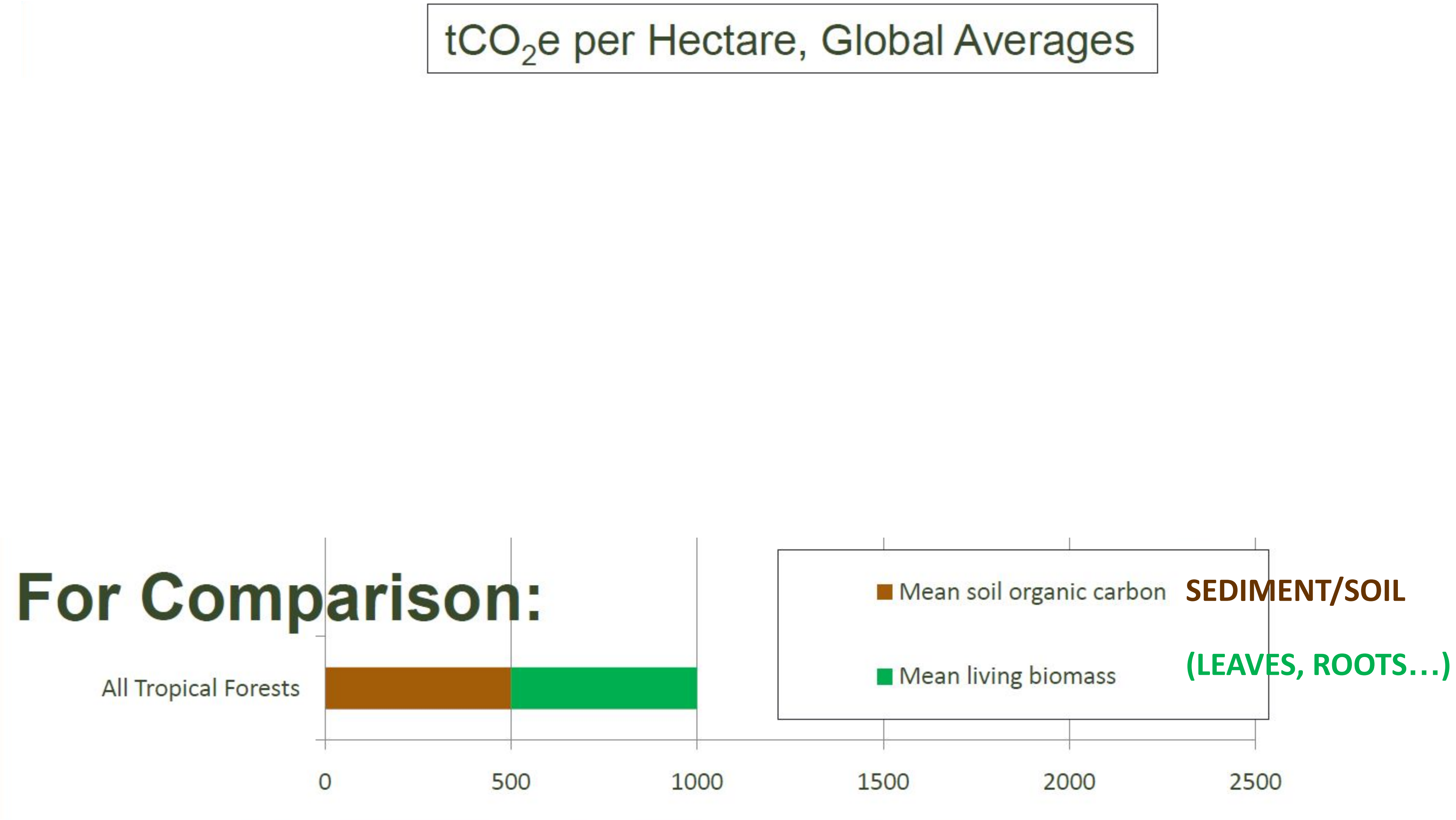
Coastal Habitats Store Carbon

Rates of carbon sequestration similar to terrestrial forests (small area but high sequestration rates)



R. Griffis, NOAA Fisheries Service, 2011

In coastal habitats, most carbon is stored in sediments and less in biomass



Sources: IUCN, Duke Nicholas Institute, Source: Murray, Brian, Linwood Pendleton, W. Aaron Jenkins, and Samantha Sifleet. 2011. Green Payments for Blue Carbon: Economic Incentives for Protecting Threatened Coastal Habitats. Nicholas Institute Report. NI R 11-04

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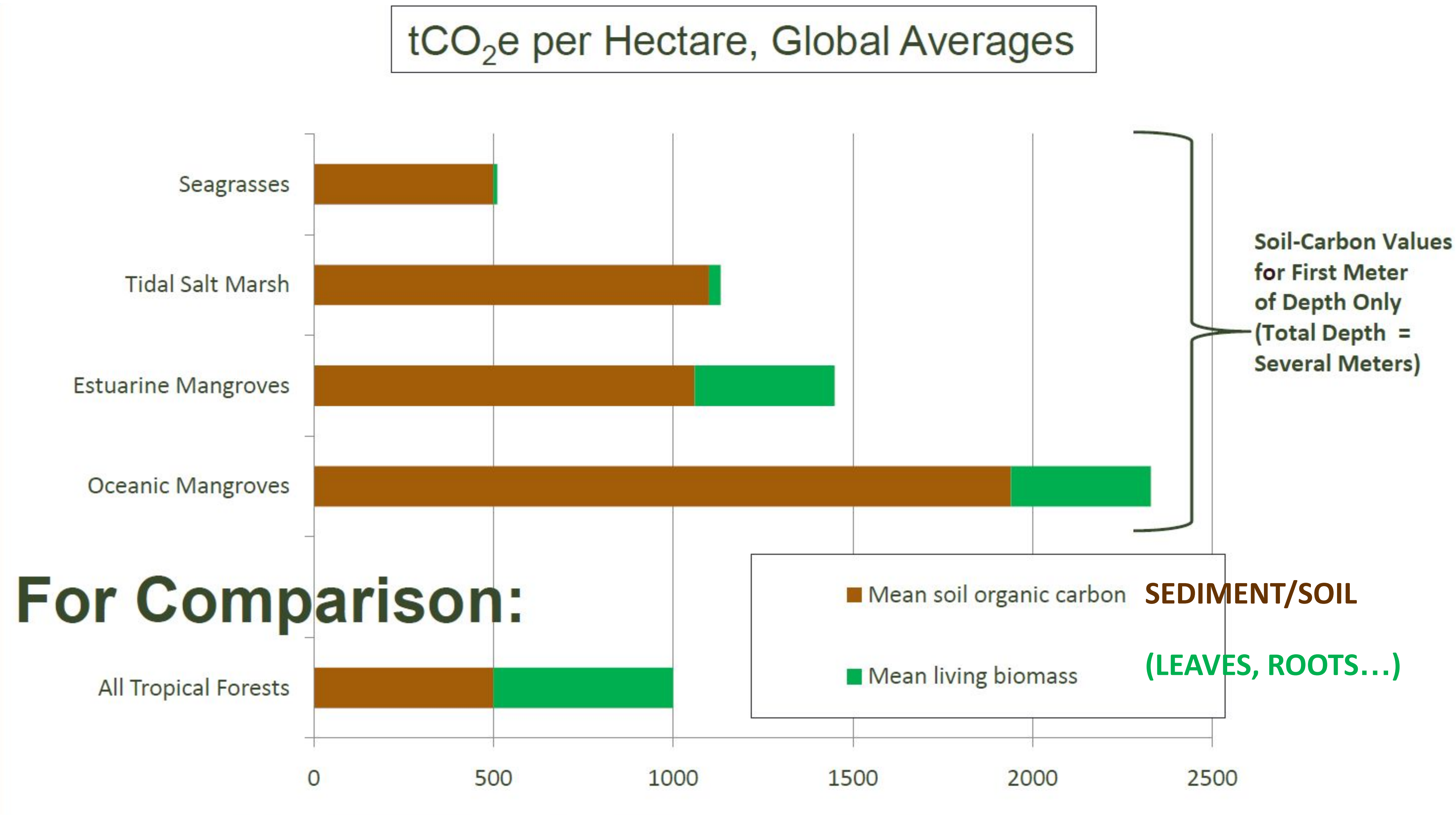


Sources: IUCN, Duke Nicholas Institute, Source: Murray, Brian, Linwood Pendleton, W. Aaron Jenkins, and Samantha Sifleet. 2011. Green Payments for Blue Carbon: Economic Incentives for Protecting Threatened Coastal Habitats. Nicholas Institute Report. NI R 11-04

These coastal systems are being rapidly lost and degraded

Source: Conservation International. E.Pidgeon, S. Troëng, 2011

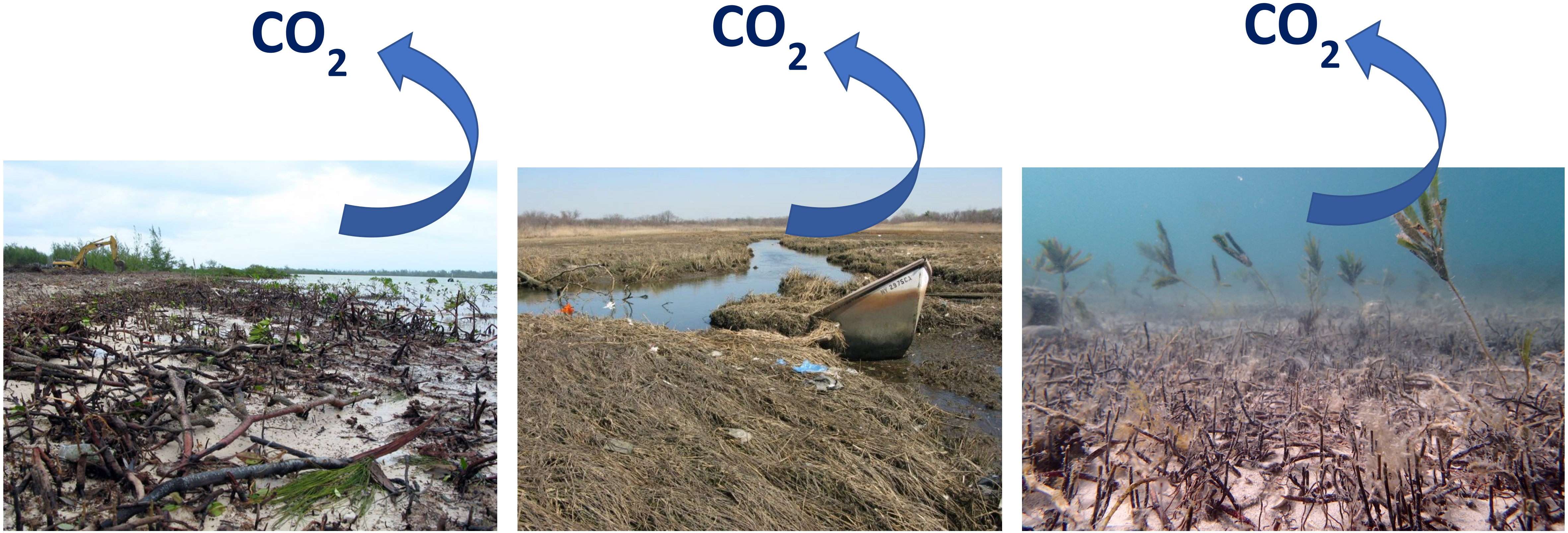
Coastal Habitat	Estimated Global Area (km2)	Annual Loss	Total Loss
Seagrass	300,000	2%	29%
Salt Marsh	400,000	2%	50% +
Mangrove	152,000	1.8%	35%

Daintree N.P. Queensland. Claire Howell

Cumberland Island Salt Marsh in Georgia (Trish Hartmann)

HELCOM. Anu Suono

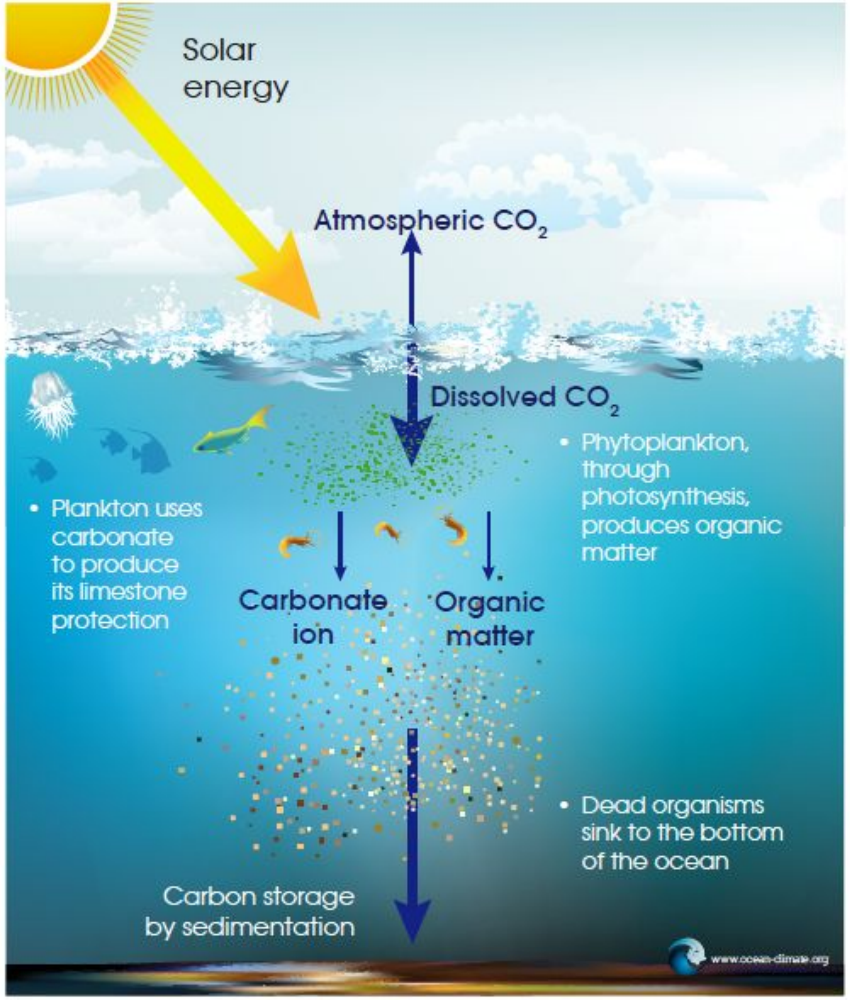
Loss = Emissions



mangroveactionproject.org matthewwills Shark Bay Ecosystem Research Project

From Carbon SINKS □ Carbon SOURCES

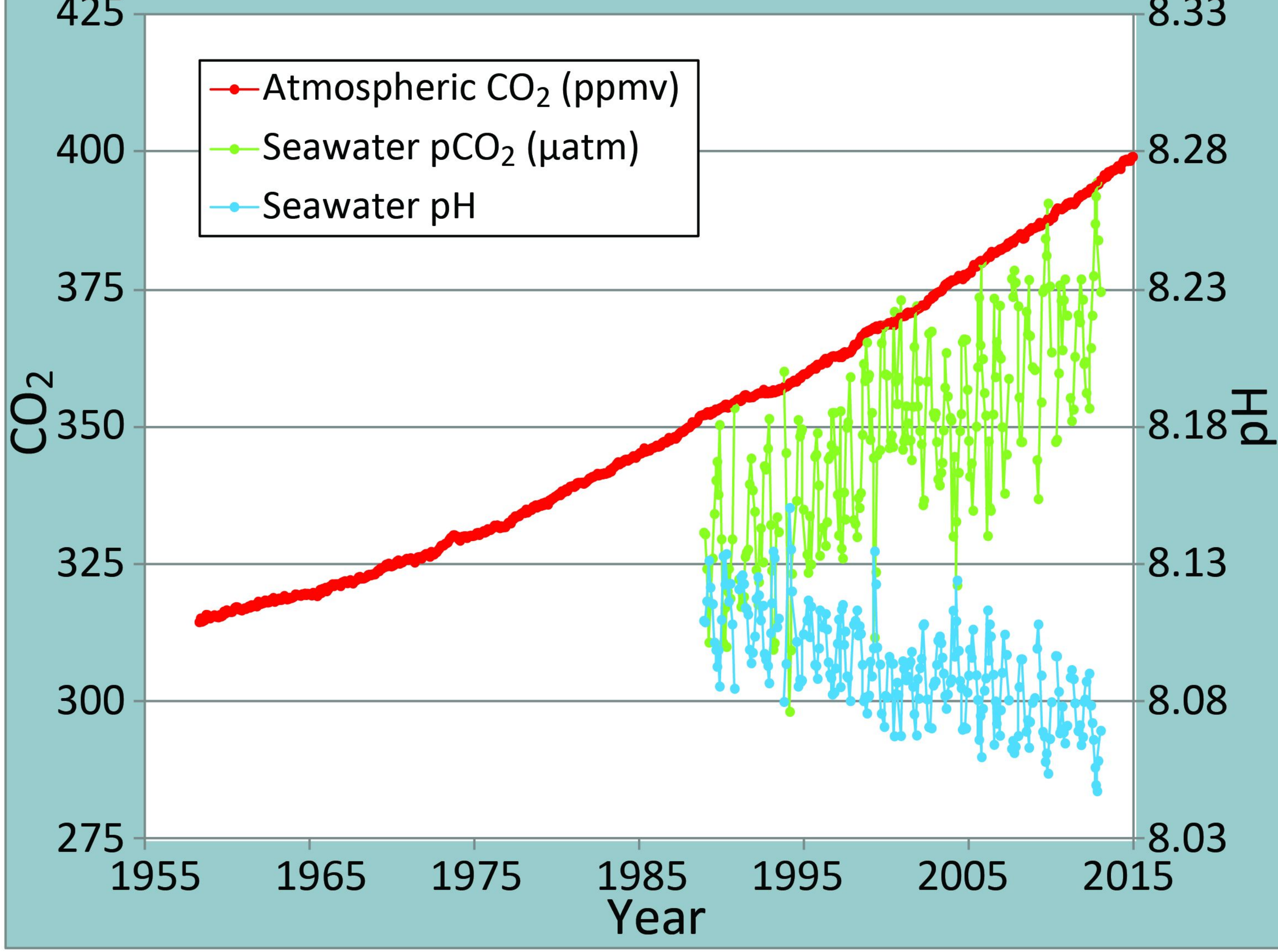
Carbon sequestration ("Blue Carbon")



Seas absorb a third of CO_2 emitted annually!!

The "evil twin" effect in the water caused by CO_2 emissions

Ocean Acidification (OA) (= low pH)



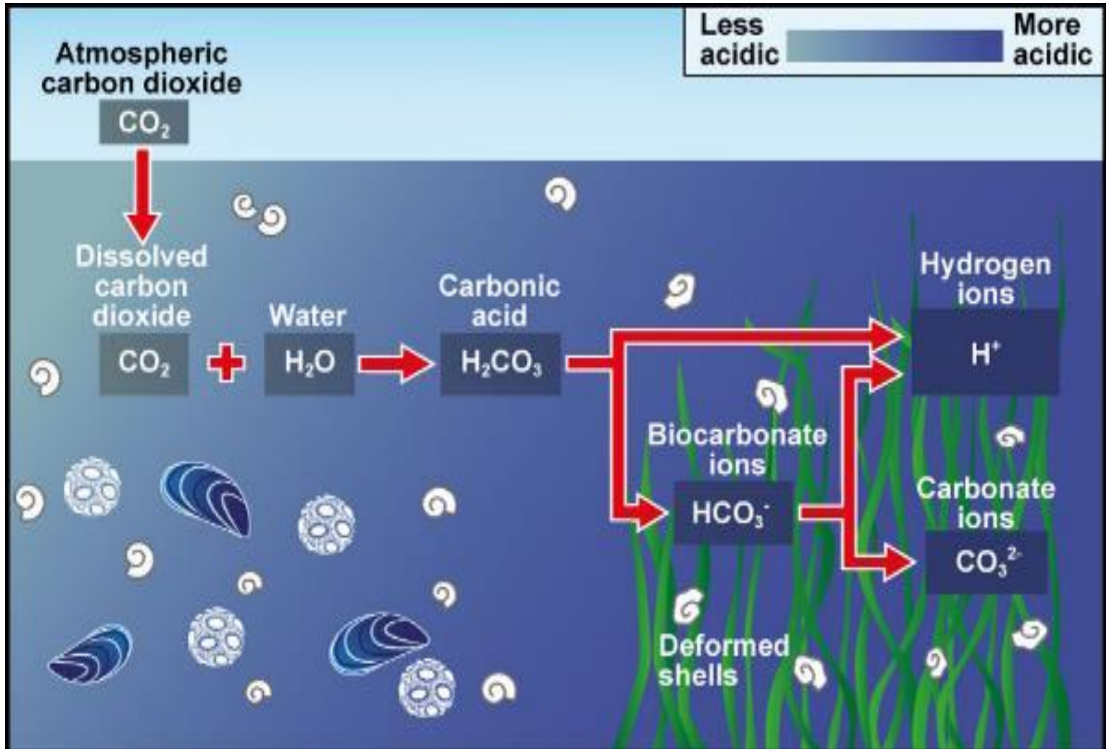
This graph shows the correlation between rising levels of carbon dioxide (CO_2) in the atmosphere at Mauna Loa with rising CO_2 levels in the nearby ocean at Station Aloha.
As more CO_2 accumulates in the ocean, the pH of the ocean decreases. (modified after R. A. Feely, Bulletin of the American Meteorological Society, July 2008).

- Carbon Dioxide (CO_2) readily dissolve in water and form **Carbonic Acid (H_2CO_3)**
- Then Carbonic Acid (H_2CO_3) dissociate in water as Bicarbonate ions (**HCO_3^-**) and Hydrogen ions (**H^+**)
- Bicarbonate ions (HCO_3^-) dissociates into and hydrogen ions (**H^+**) and carbonate ions **(CO_3^{-2})**

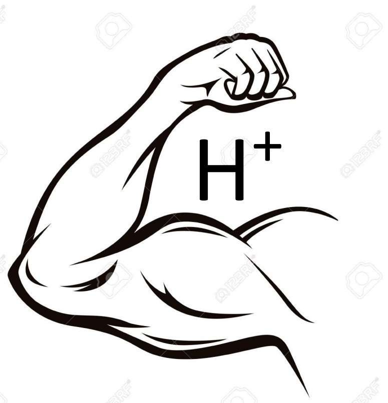
As result…

Hydrogen ions (H^+) increase!

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} \rightleftharpoons \underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{hydrogen ion}}{H^+} + \underset{\text{bicarbonate ion}}{HCO_3^-} \rightleftharpoons \underset{\text{hydrogen ion}}{H^+} + \underset{\text{carbonate ion}}{CO_3^{2-}}$$

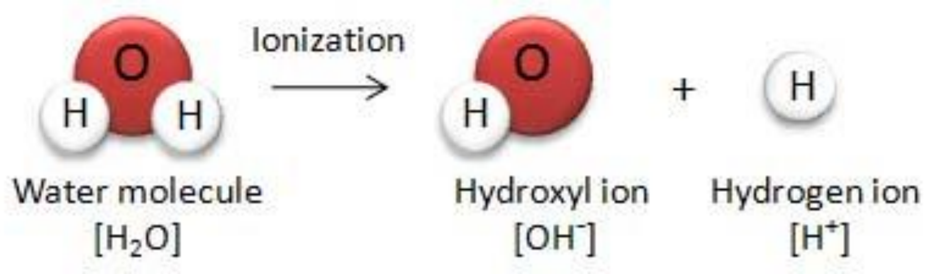


What does pH measure?



- pH from Latin and is an acronym for *"potentia hydrogenii"* - the power of hydrogen.

- pH is really a measure of the relative amount of free hydrogen (H^+) and hydroxyl ions (OH^-) in the water



- pH is reported in "logarithmic units“

$$pH = -log[H^+]$$

- Each number represents a 10-fold change in the acidity/basicness of the water.

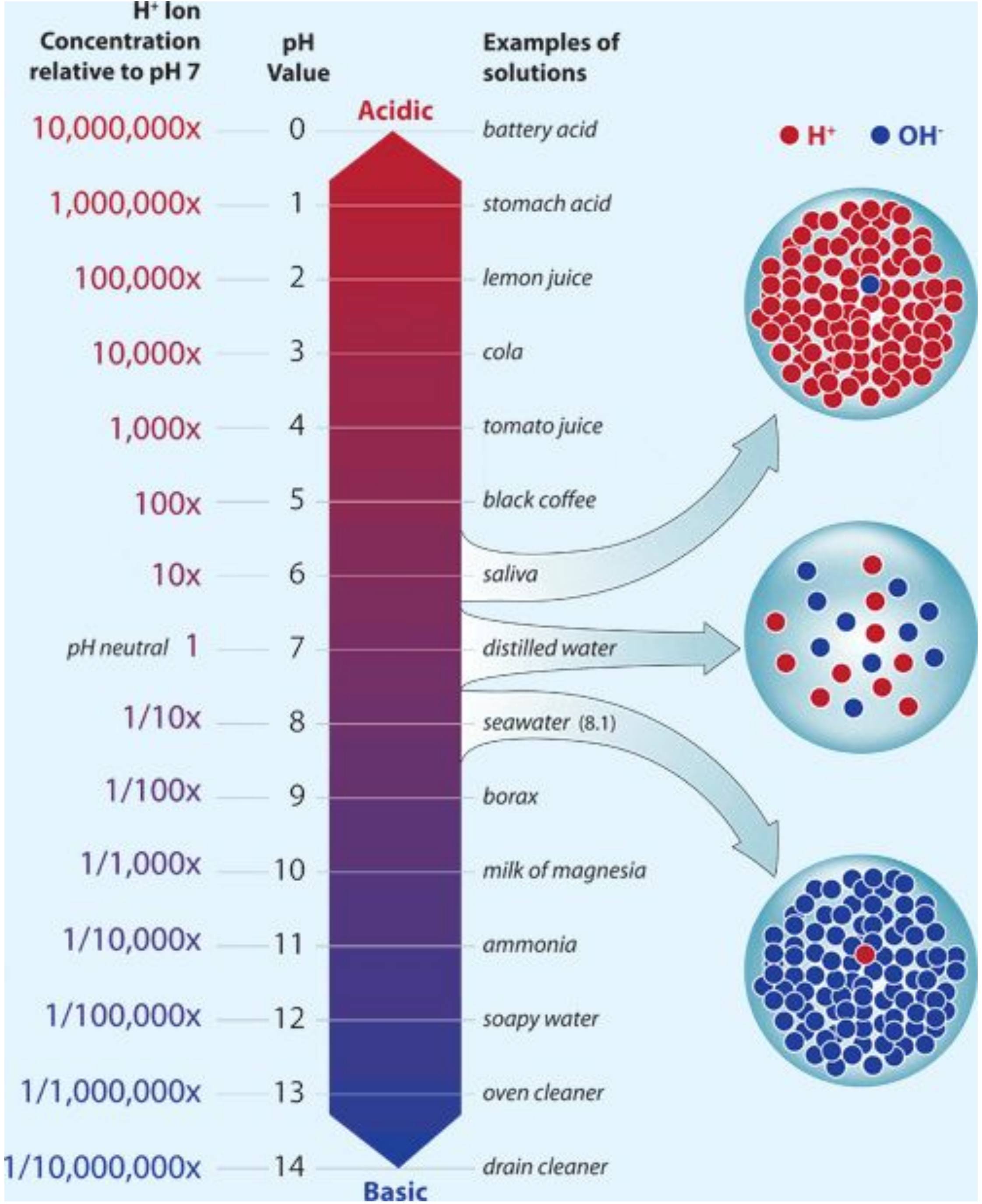
- **Water with a pH of five is ten times more acidic than water having a pH of six.**

pH = 8.2 → pH = 8.1 → pH = 7.9

30 % more acidic!!

150% more acidic!!

pH 7.9 prediction for 2100



https://www.whoi.edu/oceanus/feature/small-drop-in-ph-means-big-change-in-acidity/

ACIDIC

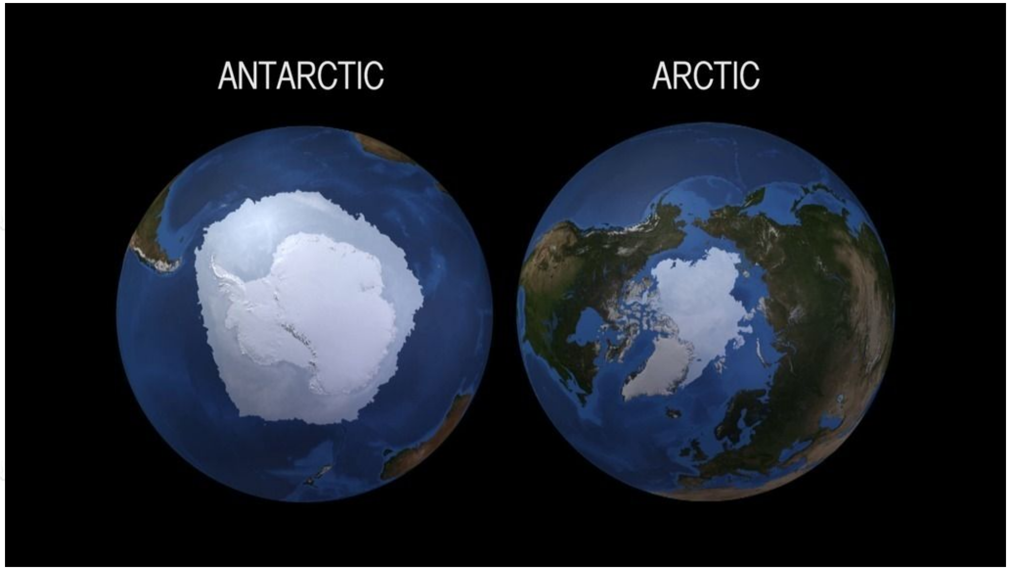
Environmental Effects	pH Value	Examples
	pH = 0	Battery acid
	pH = 1	Sulfuric acid
	pH = 2	Lemon juice, Vinegar
	pH = 3	Orange juice, Soda
All fish die (4.2)	pH = 4	**Acid rain** (4.2-4.4) **Acidic lake** (4.5)
Frog eggs, tadpoles, crayfish, and mayflies die (5.5)	pH = 5	Bananas (5.0-5.3) **Clean rain** (5.6)
Rainbow trout begin to die (6.0)	pH = 6	**Healthy lake** (6.5) Milk (6.5-6.8)
	pH = 7	Pure water
	pH = 8	Sea water, Eggs
	pH = 9	Baking soda
	pH = 10	Milk of Magnesia
	pH = 11	Ammonia
	pH = 12	Soapy water
	pH = 13	Bleach
	pH = 14	Liquid drain cleaner

NEUTRAL

BASIC

In cold water the gases dissolve better!

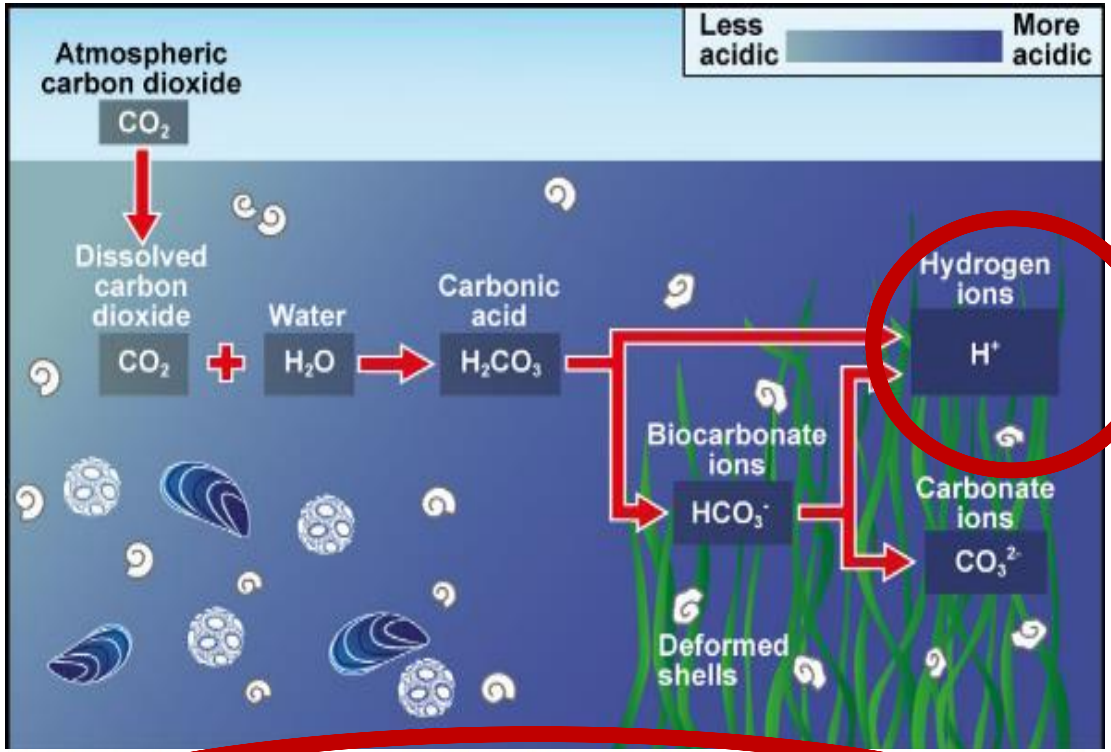
Cold areas are more affected by acidification....

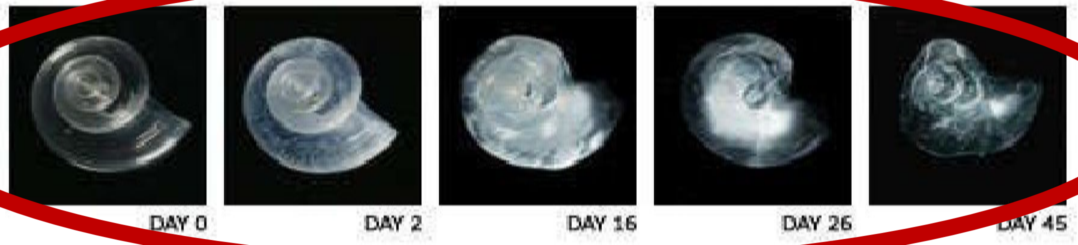


Water that has more **free hydrogen ions (H^+) is acidic**, whereas water that has more **free hydroxyl ions (OH^-) is basic**

CO_2 ↑ H^+

Increasing acidity

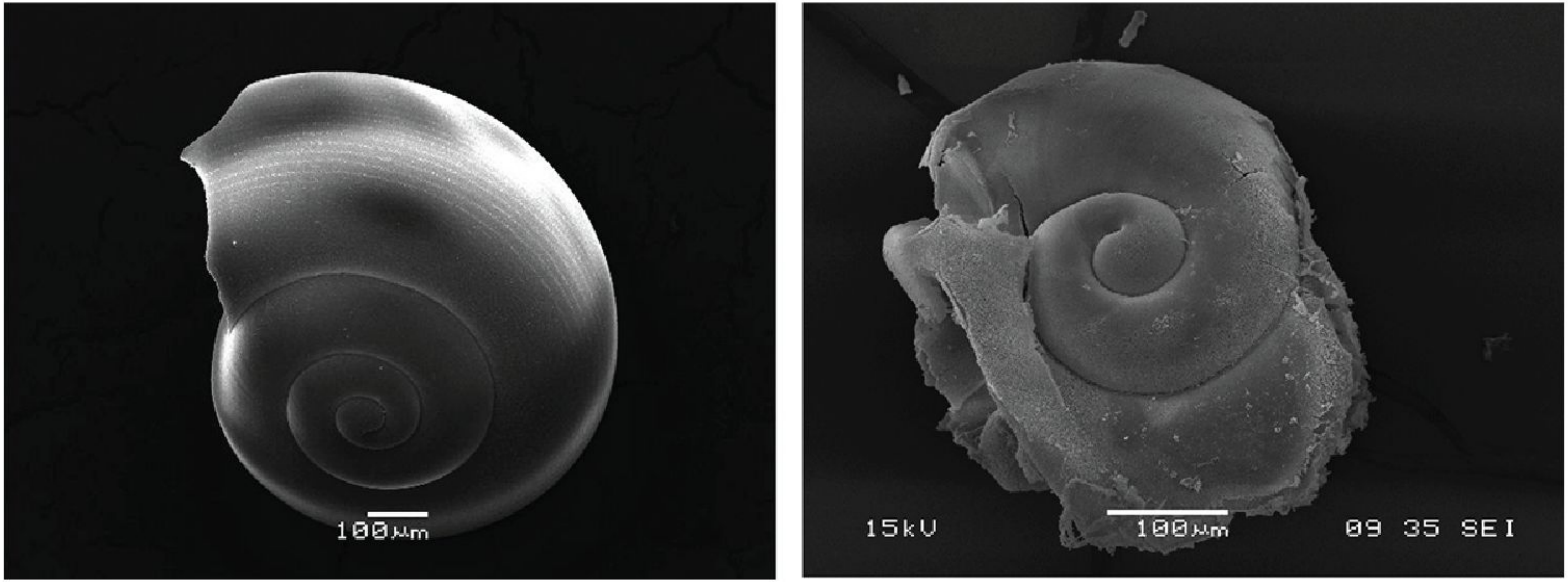




???

Ecosystem effects of ocean acidification on aquatic organisms

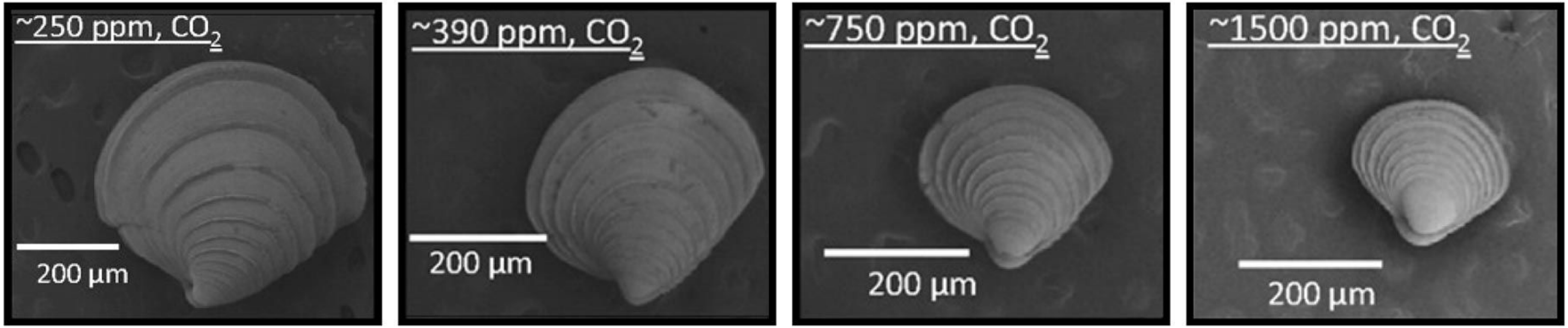
Shells Dissolve in Acidified Ocean Water



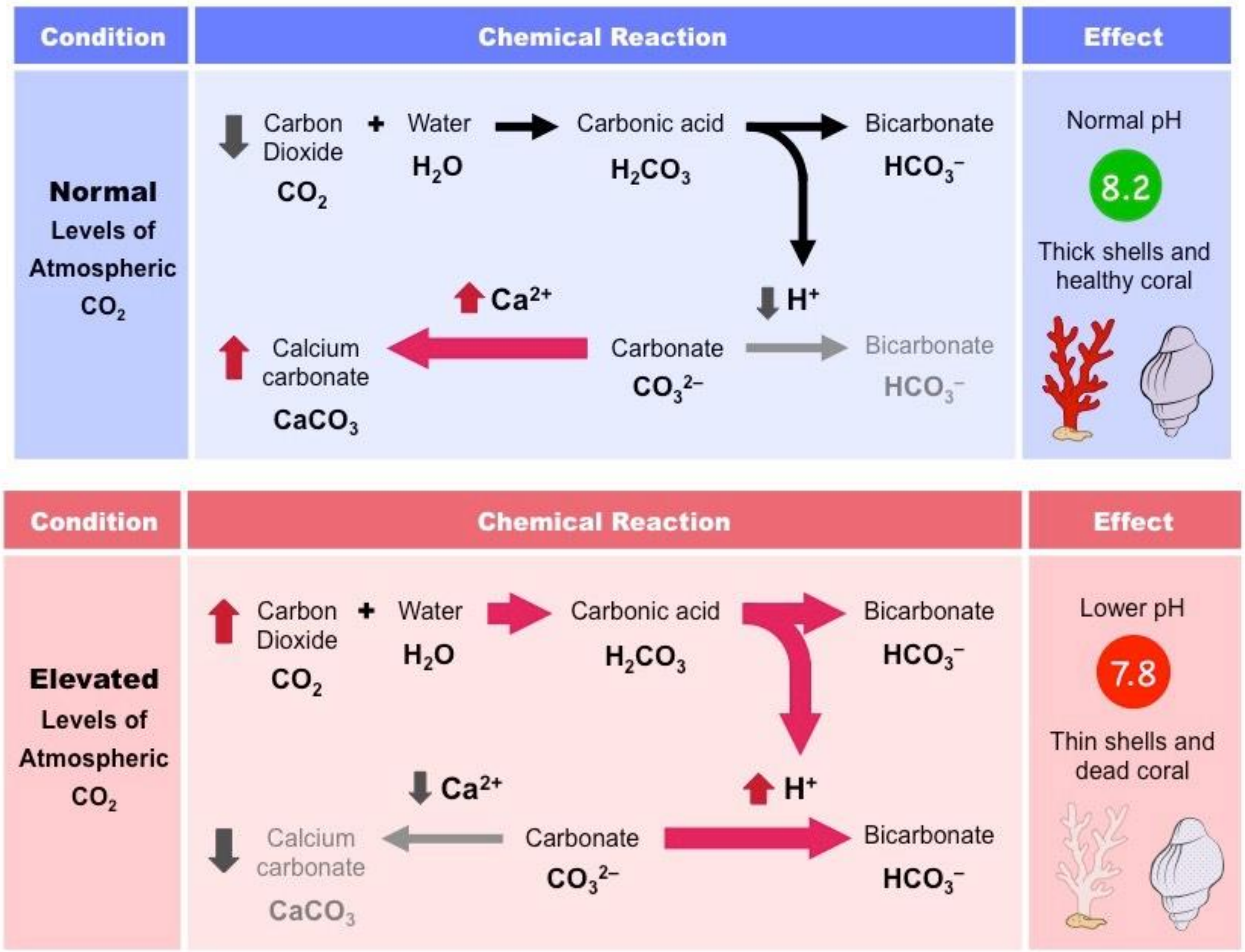
Ecosystem effects of ocean acidification on aquatic organisms

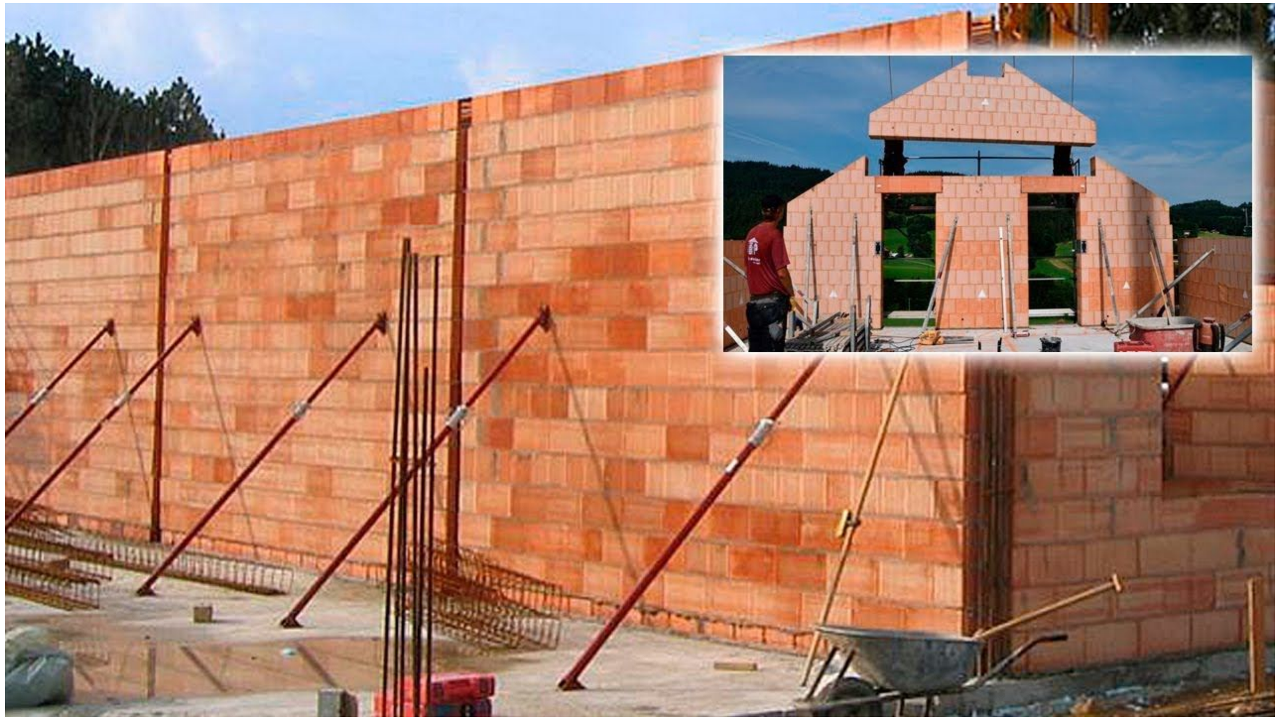
Why?

Ocean Acidification Reduces Size of Clams



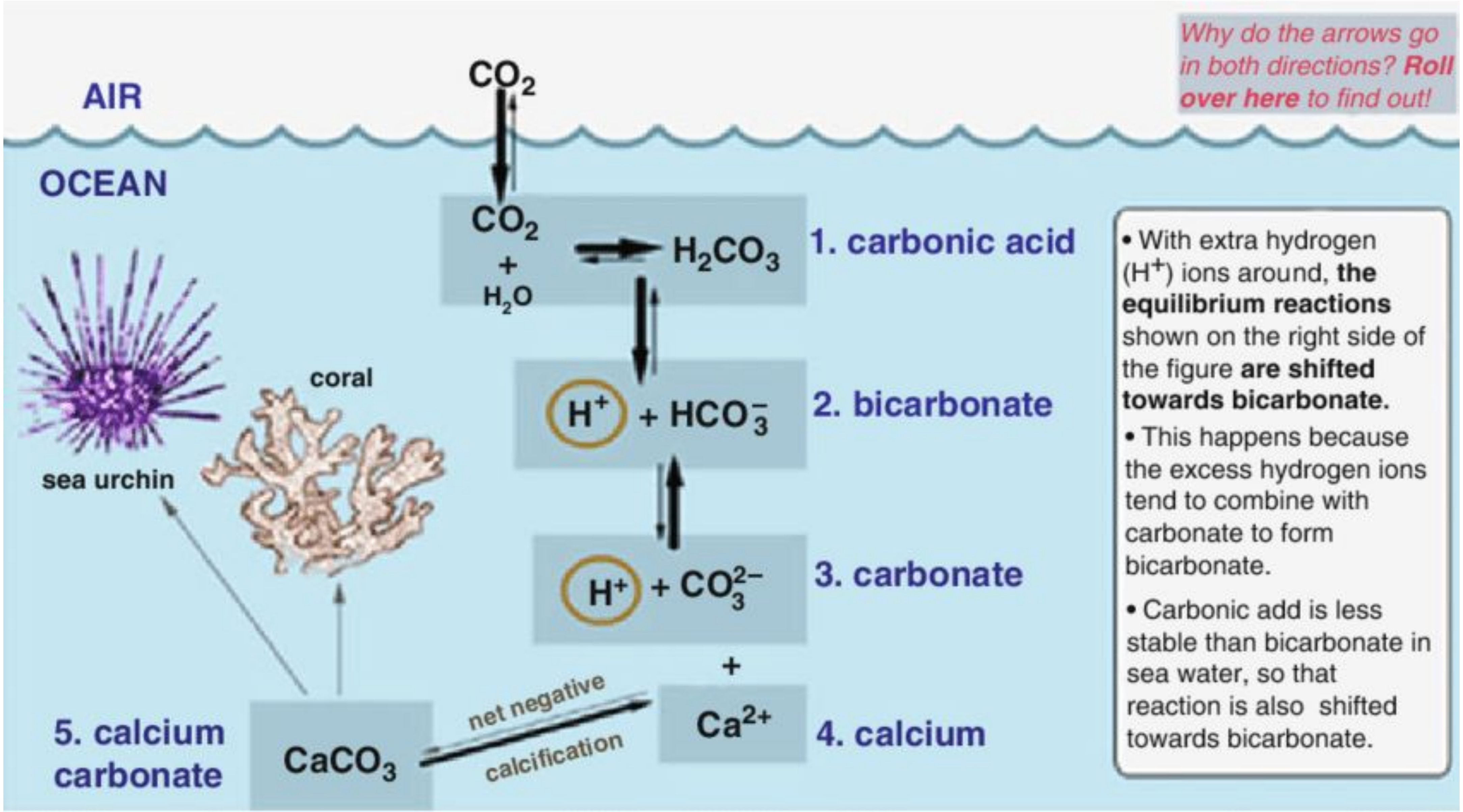
Calcification reaction: Calcium carbonate $CaC0_3$



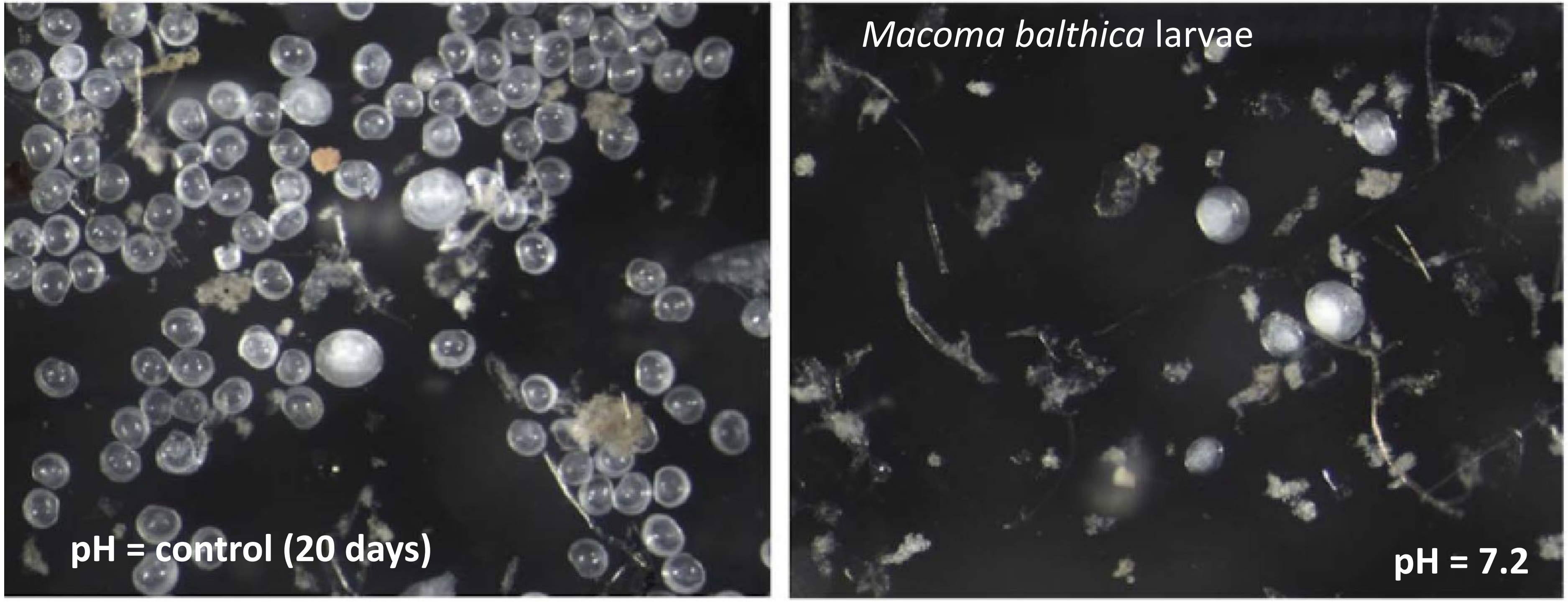


Calcification = Building a brick house….

But the bricks are being removed…!! $CaC0_3$


Why do the arrows go in both directions? Roll over here to find out!
AIR
OCEAN
CO_2
CO_2 + H_2O → H_2CO_3
1. carbonic acid
H^+ + HCO_3^-
2. bicarbonate
H^+ + CO_3^{2-}
3. carbonate
+
Ca^{2+}
4. calcium
5. calcium carbonate
$CaCO_3$
net negative
calcification
coral
sea urchin
• With extra hydrogen (H^+) ions around, the equilibrium reactions shown on the right side of the figure are shifted towards bicarbonate.
• This happens because the excess hydrogen ions tend to combine with carbonate to form bicarbonate.
• Carbonic add is less stable than bicarbonate in sea water, so that reaction is also shifted towards bicarbonate.

How will Baltic clams build shells in the future with dissolution effects stepping in?



Jansson A, Norkko J, Norkko A (2013) Effects of reduced pH on *Macoma balthica* larvae from a system with naturally fluctuating pH-dynamics. PLoS ONE 8(6):e68198

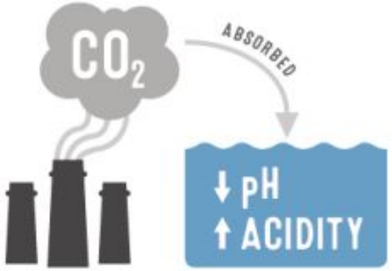
Ocean acidification and hypoxia are related – respiration of organic matter releases CO_2

Hypoxia

CARBON DIOXIDE AND OCEAN ACIDIFICATION

Climate change is a much-discussed effect of rising carbon dioxide levels, but they can also affect our oceans. This graphic takes a look at how.

THE BASICS



Atmospheric carbon dioxide has increased by 40% from pre-industrial levels due to burning of fossil fuels and deforestation. Ocean acidification occurs when atmospheric carbon dioxide dissolves in seawater.

PRE-INDUSTRIAL	2013	2100
pH 8.2	pH 8.1 (25% MORE ACIDIC)	pH 7.7 (PROJECTED)

Acidity and alkalinity are measured on the logarithmic pH scale. A pH over 7 is alkaline; below 7 is acidic. A change of one unit represents a tenfold change in acidity or alkalinity. Seawater is alkaline, but average ocean surface pH has dropped by 0.1 since pre-industrial times, a 25% increase in acidity.

THE CHEMISTRY OF OCEAN ACIDIFICATION

Atmospheric carbon dioxide dissolves in seawater (1) and reacts with the water to form carbonic acid (2). Carbonic acid dissociates (splits up) into its ions (3); hydrogen ions produced by this dissociation increase acidity, lowering seawater pH. Increased atmospheric carbon dioxide ultimately produces more hydrogen ions, lowering pH further.

CO_2 — ATMOSPHERIC CARBON DIOXIDE

(1) ↓

$$CO_2 + H_2O \overset{(2)}{\rightleftharpoons} H_2CO_3 \overset{(3)}{\rightleftharpoons} H^+ + HCO_3^-$$

DISSOLVED CARBON DIOXIDE ($CO_2 + H_2O$) — CARBONIC ACID (H_2CO_3) — HYDROGEN IONS + BICARBONATE IONS ($H^+ + HCO_3^-$)

(4) ⇅

HYDROGEN IONS + CARBONATE IONS: $2H^+ + CO_3^{2-}$

Hydrogencarbonate ions can dissociate further to form carbonate ions (4) but this is less favoured. Consequently hydrogencarbonate ions are the most abundant form of inorganic carbon in the oceans. Calcium carbonate can also react with dissolved carbon dioxide in seawater to form more hydrogencarbonate ions (5).

(5) $CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca^{2+} + 2HCO_3^-$

THE EFFECTS OF OCEAN ACIDIFICATION

1 EFFECT ON CALCIFYING ORGANISMS AND CORAL

pH 8.1 → LESS CARBONATE DISSOLUTION

$$CaCO_3 \rightleftharpoons Ca^{2+} + CO_3^{2-}$$

pH 7.7 → INCREASED CARBONATE DISSOLUTION

As ocean pH drops, hydrogen ions react with carbonate ions. Calcifying organisms such as clams, oysters and crustaceans use the carbonate ions from seawater to make shells. When calcium carbonate is undersaturated in seawater, their shells can start dissolving. Coral skeletons can also be affected.

2 EFFECT ON FOOD WEBS AND FISHING

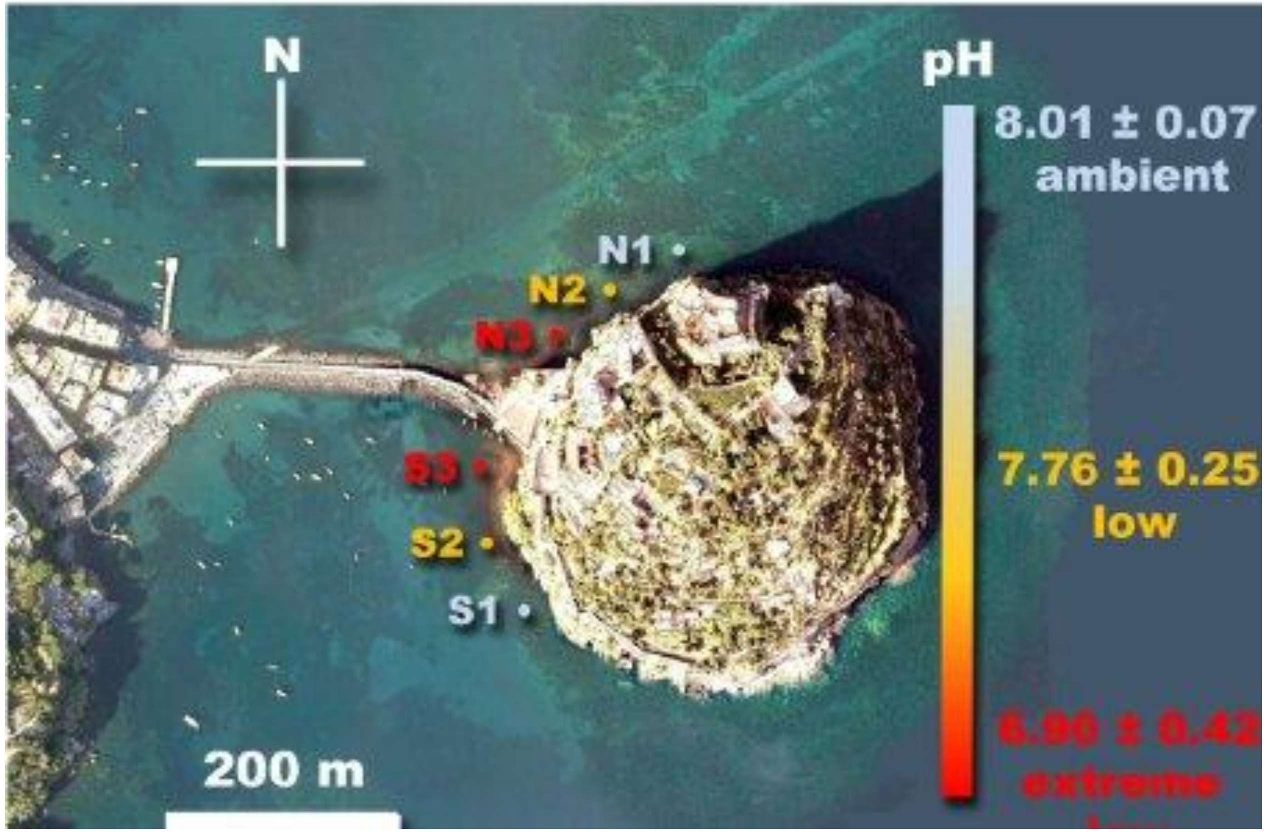
Calcifying organisms are at the root of a number of marine food webs. Negative effects on their population could have a knock-on effect on species that feed on them, impacting fishing industries.

3 EFFECTS ON ANIMAL CHEMICAL SIGNALLING

pH 8.1 ✔ EGG VENTILATION (VS. CONTROL) — pH 7.7 ✘ EGG VENTILATION (VS. CONTROL)

Many marine species use chemical signals for detecting predators, settlement, and reproduction. Ocean acidification can alter signalling molecules, which could in turn have potentially detrimental effects on a number of different species.


Castello Aragonese (Italy)
It is a 14th century castle off the coast of Italy
Torture Museum
Underwater



There are volcanic vents naturally release bubbles of carbon dioxide gas, creating different levels of acidity

THE CARBON DIOXIDE VENTS OF ISCHIA, ITALY, A NATURAL SYSTEM TO ASSESS IMPACTS OF OCEAN ACIDIFICATION ON MARINE ECOSYSTEMS: AN OVERVIEW OF RESEARCH AND COMPARISONS WITH OTHER VENT SYSTEMS

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Abstract

As the ocean continues to take up carbon dioxide (CO_2), it is difficult to predict the future of marine ecosystems. Natural CO_2 vent sites, mainly of volcanic origin, that provide a pH gradient are useful as a proxy to investigate ecological effects of ocean acidification. The effects of decreased pH can be assessed at increasing levels of organisation, from the responses of individuals of a species up through populations and communities to whole ecosystems. As a natural laboratory, CO_2 vent sites incorporate a range of environmental factors, such as gradients of nutrients, currents and species interactions that cannot be replicated in the laboratory or mesocosms, with the caveat that some vent systems have confounding factors such as hydrogen sulphide and metals. The first CO_2 vent sites to be investigated in an ocean acidification context were the vents at the Castello Aragonese on the island of Ischia, Italy. The gas released is primarily CO_2 with no evidence of toxic substances. They have been the focus of a wealth of studies, which are reviewed here and in context with research at

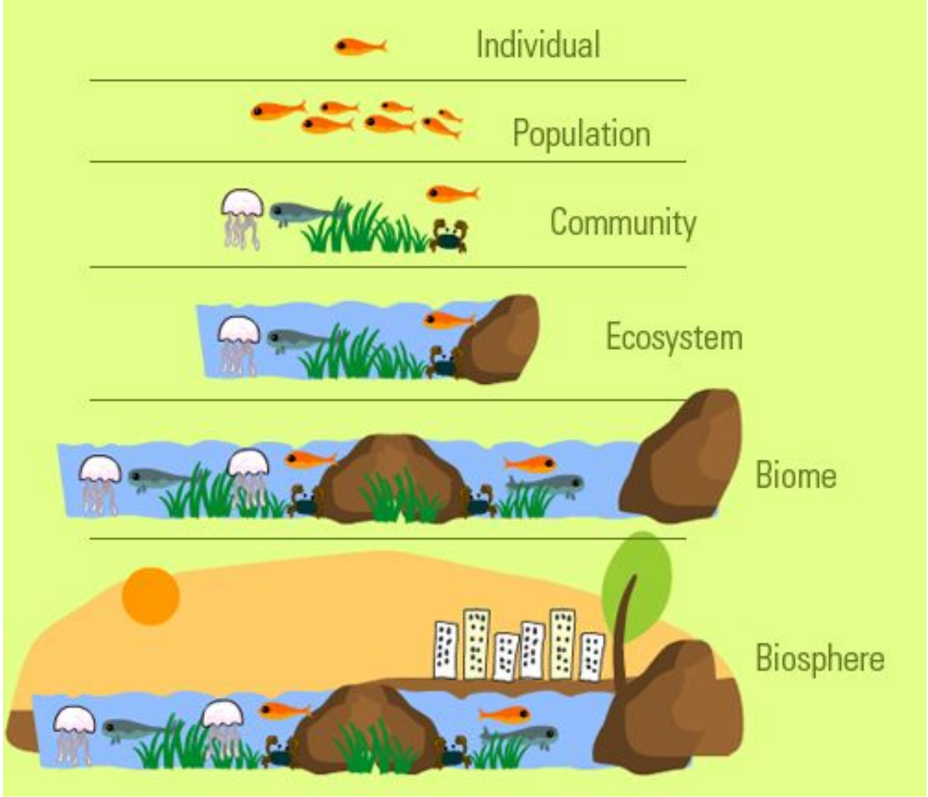
In Moodle (Literature)

Video

Readings:

In Moodle: THE CARBON DIOXIDE VENTS OF ISCHIA, ITALY, A NATURAL SYSTEM TO ASSESS IMPACTS OF OCEAN ACIDIFICATION ON MARINE ECOSYSTEMS: AN OVERVIEW OF RESEARCH AND COMPARISONS WITH OTHER VENT SYSTEMS

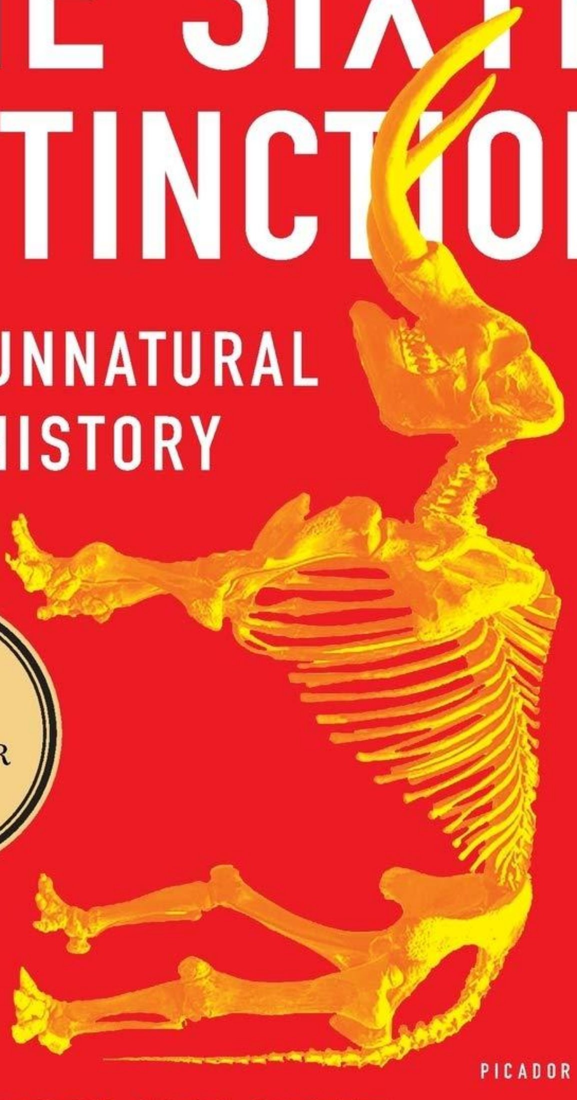
Abstract “The effects of decreased pH can be assessed at increasing levels of organisation, from the responses of individuals of a species up through populations and communities to whole ecosystems.”



NEW YORK TIMES BESTSELLER

THE SIXTH EXTINCTION

AN UNNATURAL HISTORY



WINNER *of the* PULITZER PRIZE

PICADOR

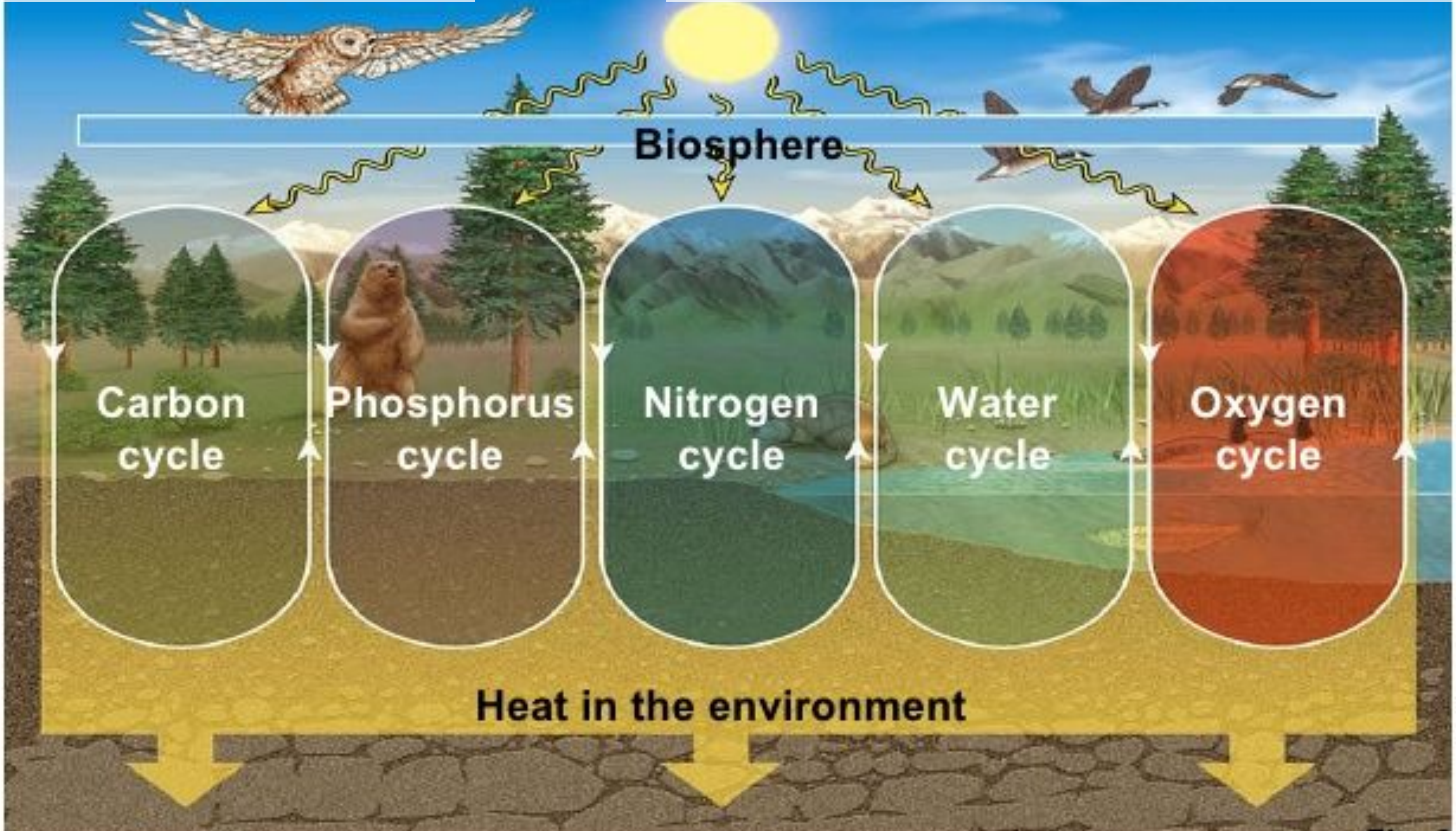
ELIZABETH KOLBERT

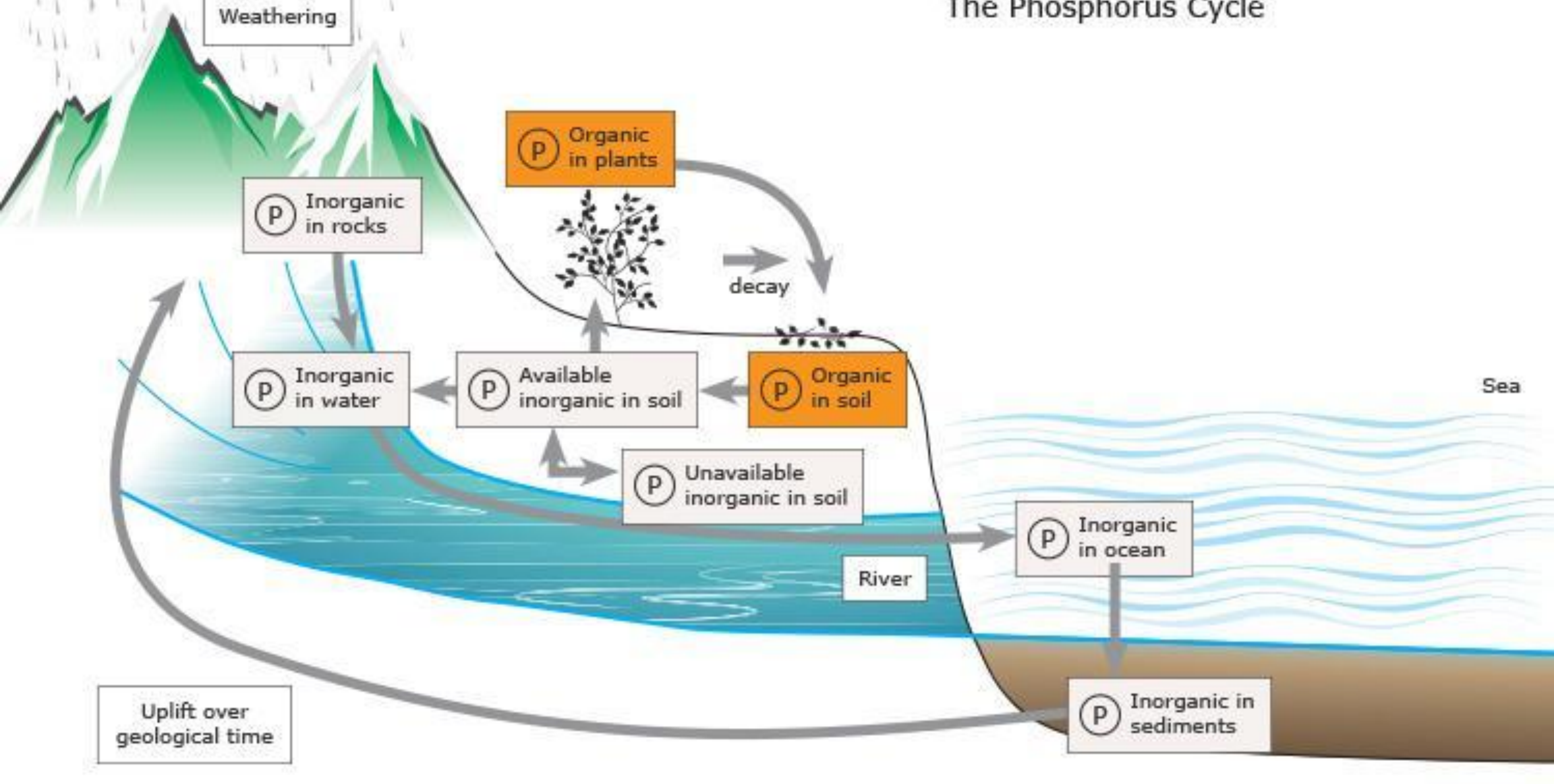
Author of *FIELD NOTES FROM A CATASTROPHE*

Algal bloom increase or decrease the pH?

Why?

ECOLOGICAL CYCLES **The essentials – water and nutrients**




The Phosphorus Cycle
Weathering
P Organic in plants
P Inorganic in rocks
decay
P Inorganic in water
P Available inorganic in soil
P Organic in soil
Sea
P Unavailable inorganic in soil
P Inorganic in ocean
River
P Inorganic in sediments
Uplift over geological time

BALTIC SEA ACTION GROUP (BSAG)

https://carbonaction.org/front-page/