CORAL REEFS UNDER GLOBAL CHANGE

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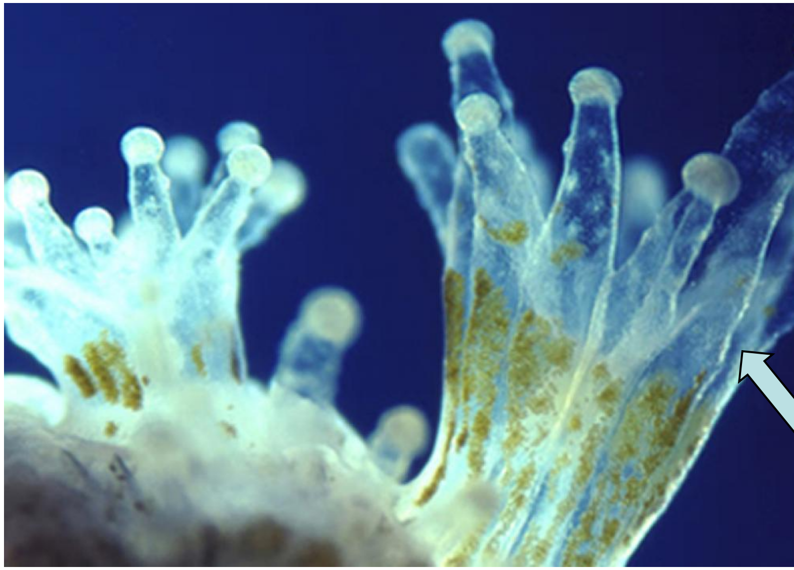
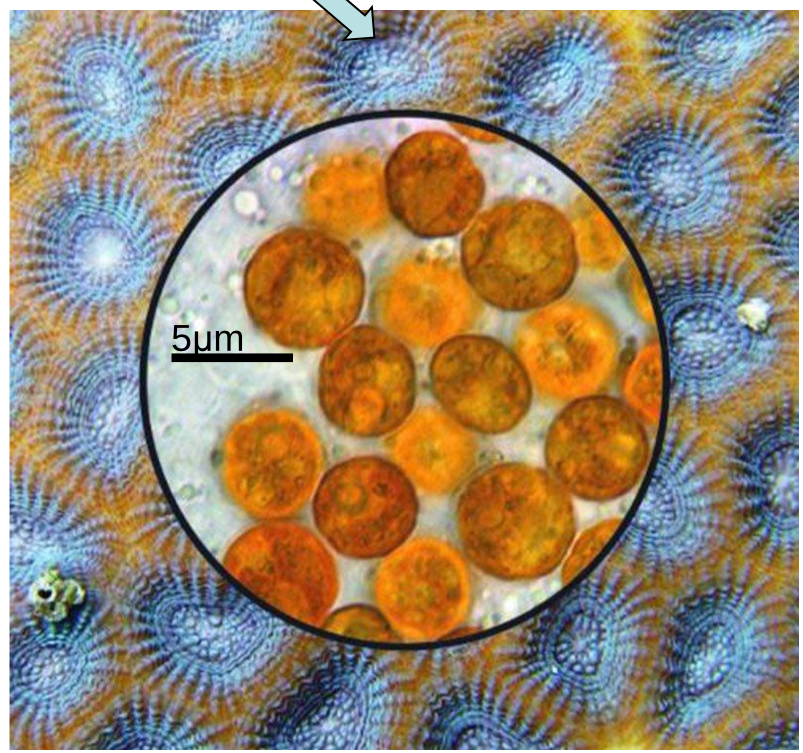
Coral reefs

- The most diverse and complex ecosystem in the ocean with thousands of species
- Highly productive system. Rate of gross photosynthesis is 50-100 time higher then in the next by open ocean
- Multiple symbiotic relations from the cell level to the ecosystem level
- An important component of the global carbon cycle, despite its small area (0.2%)
- Economically important (tourism, fisheries etc)



The corals belong to the Coelenterates (Medusa, Anemonies). Most of them are colonial built of thousands of polyps having stinginting tentacles and myriads of symbiotic algae (10^6 cm^{-2}). They build unique $CaCO_3$ skeletons that build the coral reefs.

One polyp with symbiotic algae



Light Enhanced Calcification

(the common dogma)

CO_2 is taken by the algae for photosynthesis and this promotes calcification

(and vice versa: calcification enhances photosynthesis)

Calcification

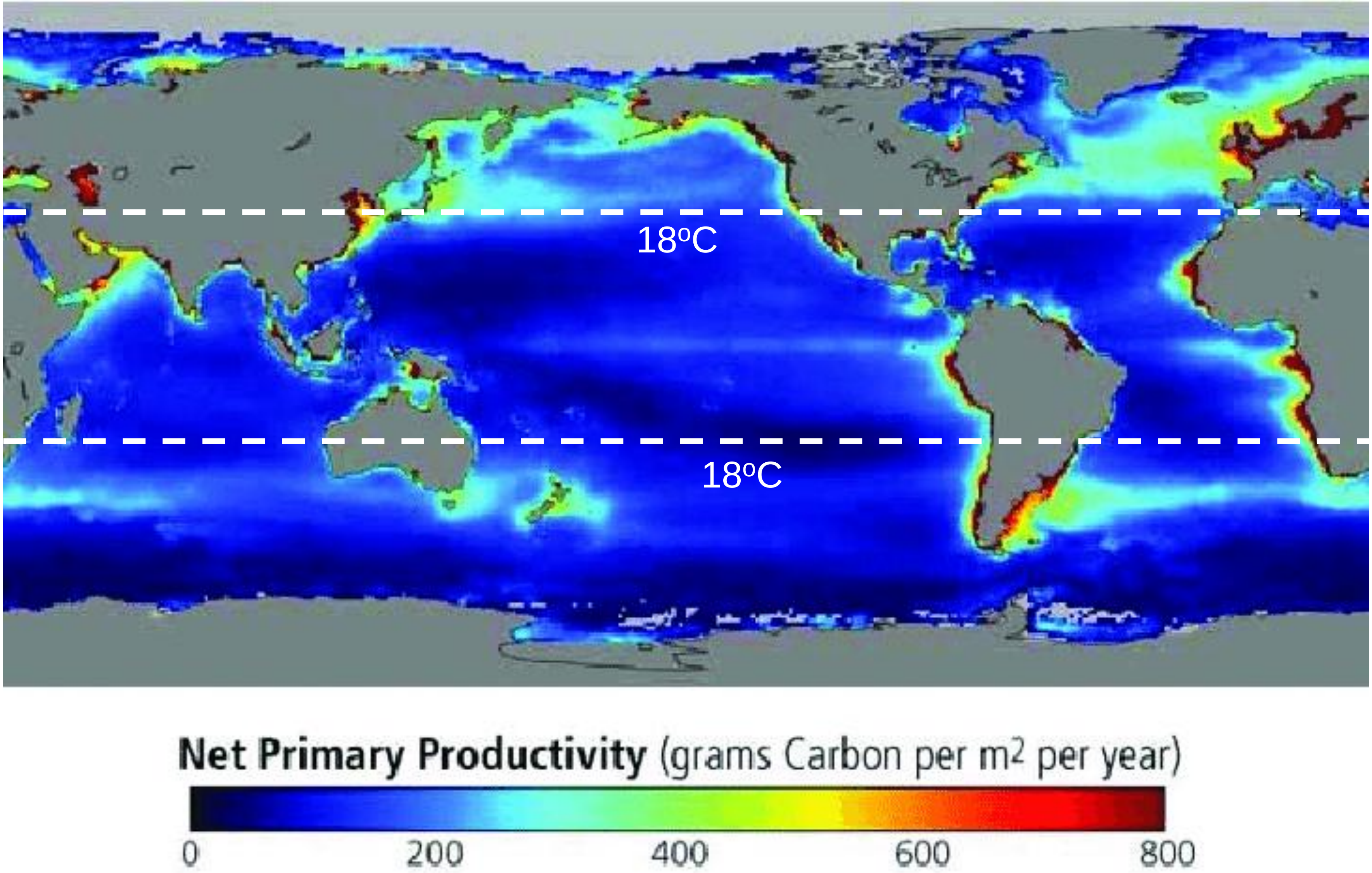
$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$$

$$CO_2 + H_2O \rightarrow CH_2O + O_2$$

Photosynthesis

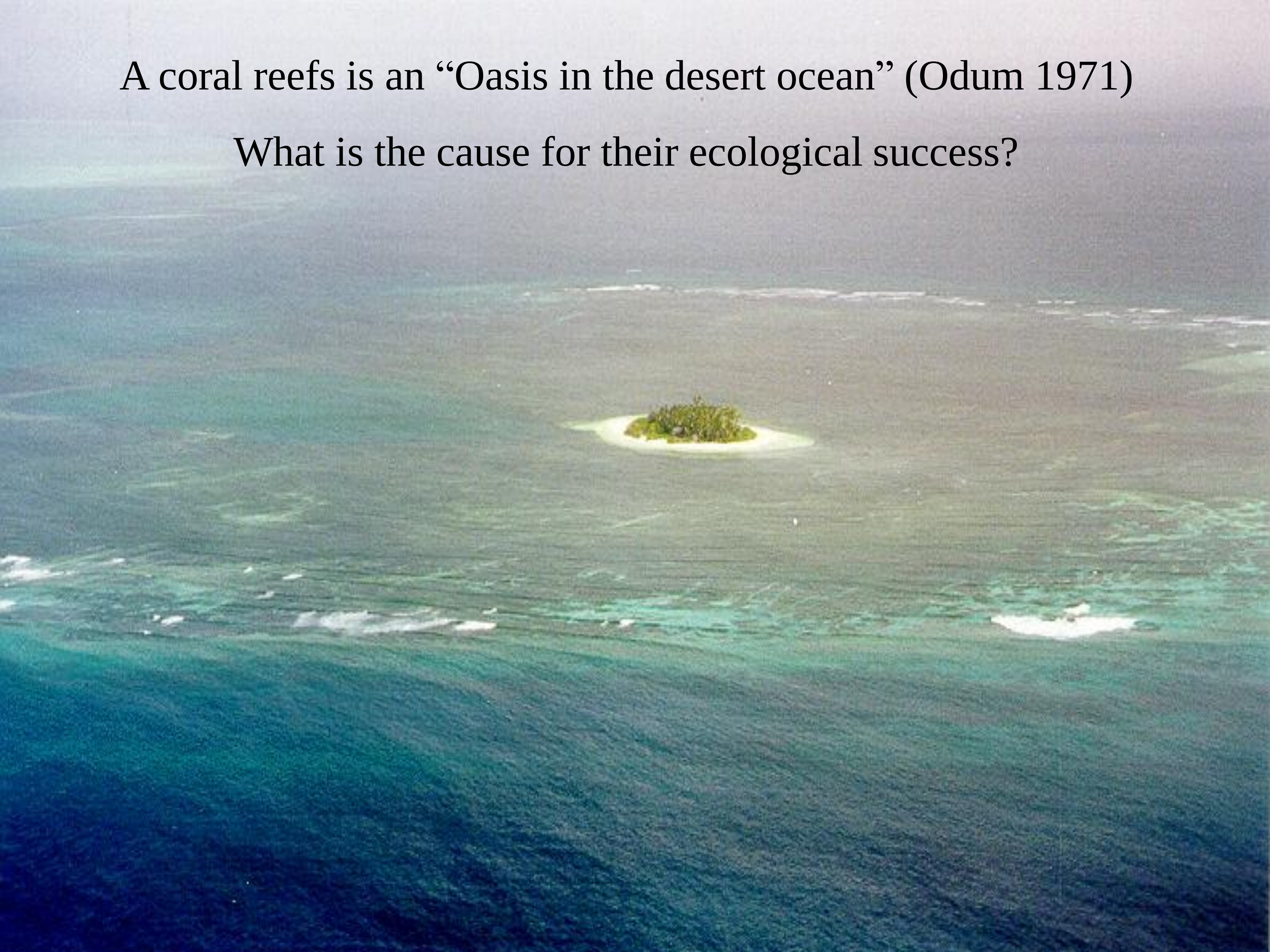
After Goreau TF, 1959

Coral reefs are found in the oligotrophic parts of the ocean – the blue “desert”



The nutrient paradox of coral reefs 1

- The ecologist Odum was the first to point this paradox: "OASIS IN THE DESERT OCEAN"
- Coral reefs thrive in subtropical waters where nutrient concentrations are very low, and primary productivity is 0.1- 0.2 gC m^{-2} day^{-1}.
- Primary productivity within coral reefs is 10-15 gC m^{-2} day^{-1}, 100 times more then in the surrounding water.
- The traditional ecological explanation: Highly efficient nutrient recycling within the coral reef ecosystem
- But coral reefs are open systems constantly flushed by ocean currents tides and waves


A coral reefs is an “Oasis in the desert ocean” (Odum 1971)
What is the cause for their ecological success?

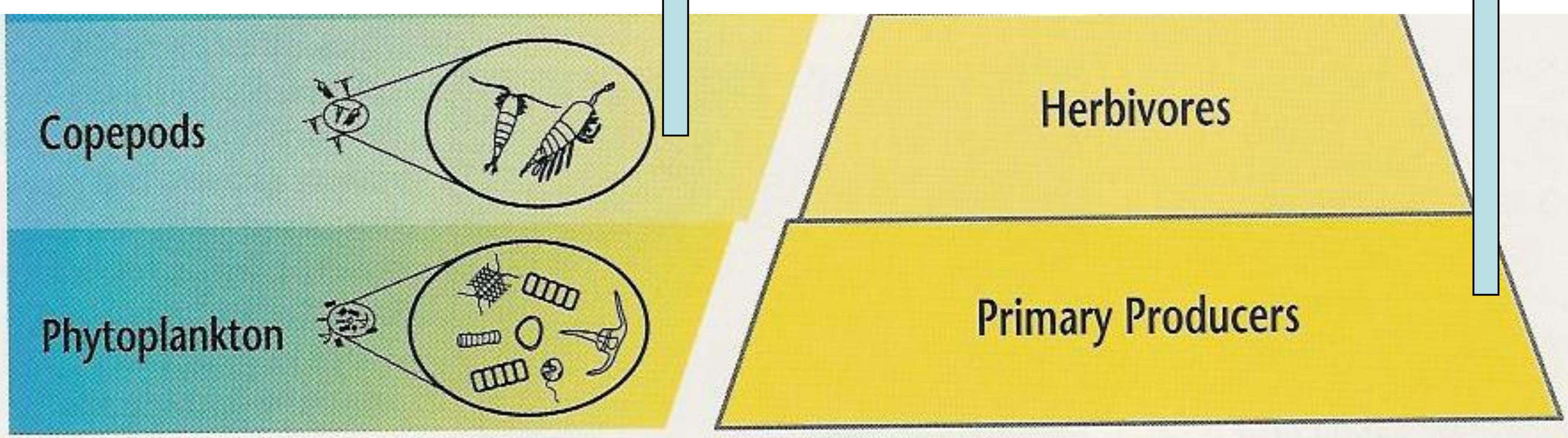
Solving the nutrient paradox of coral reefs

- We proposed that a coral reef is a huge filtering system that extract **plankton** from the oligotrophic water.
- This mega-filter is built by the corals (and other calcifyers). It stands on a solid ground and creates a wave resistant structure.
- The higher is the flow and water exchange with the open sea more plankton is supplied to the ecosystem.
- The nutrients are coming from the **particulate phase** and dissolved nutrients are released to the open sea

PLANKTON

Zooplankton (Copepods etc.)

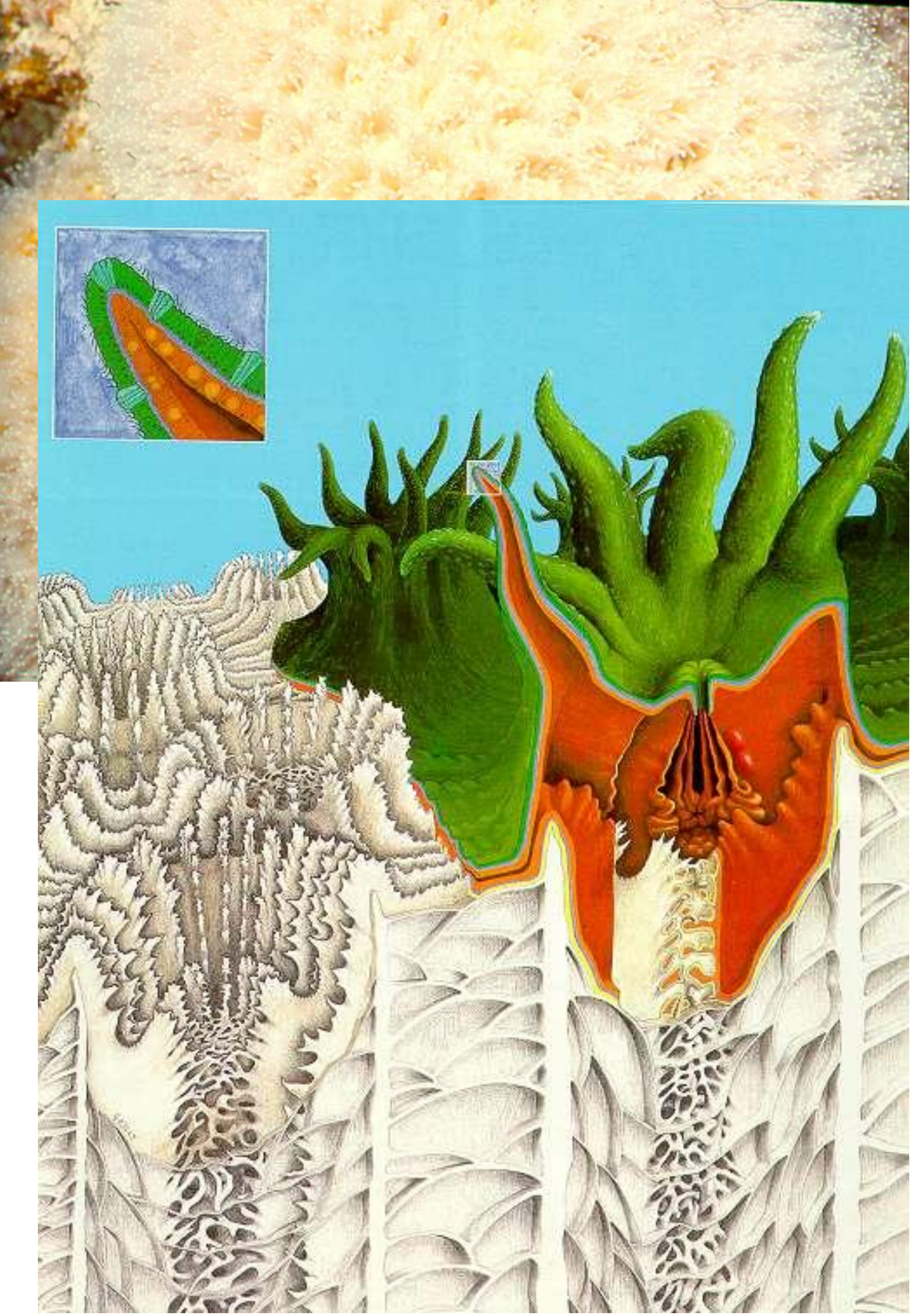
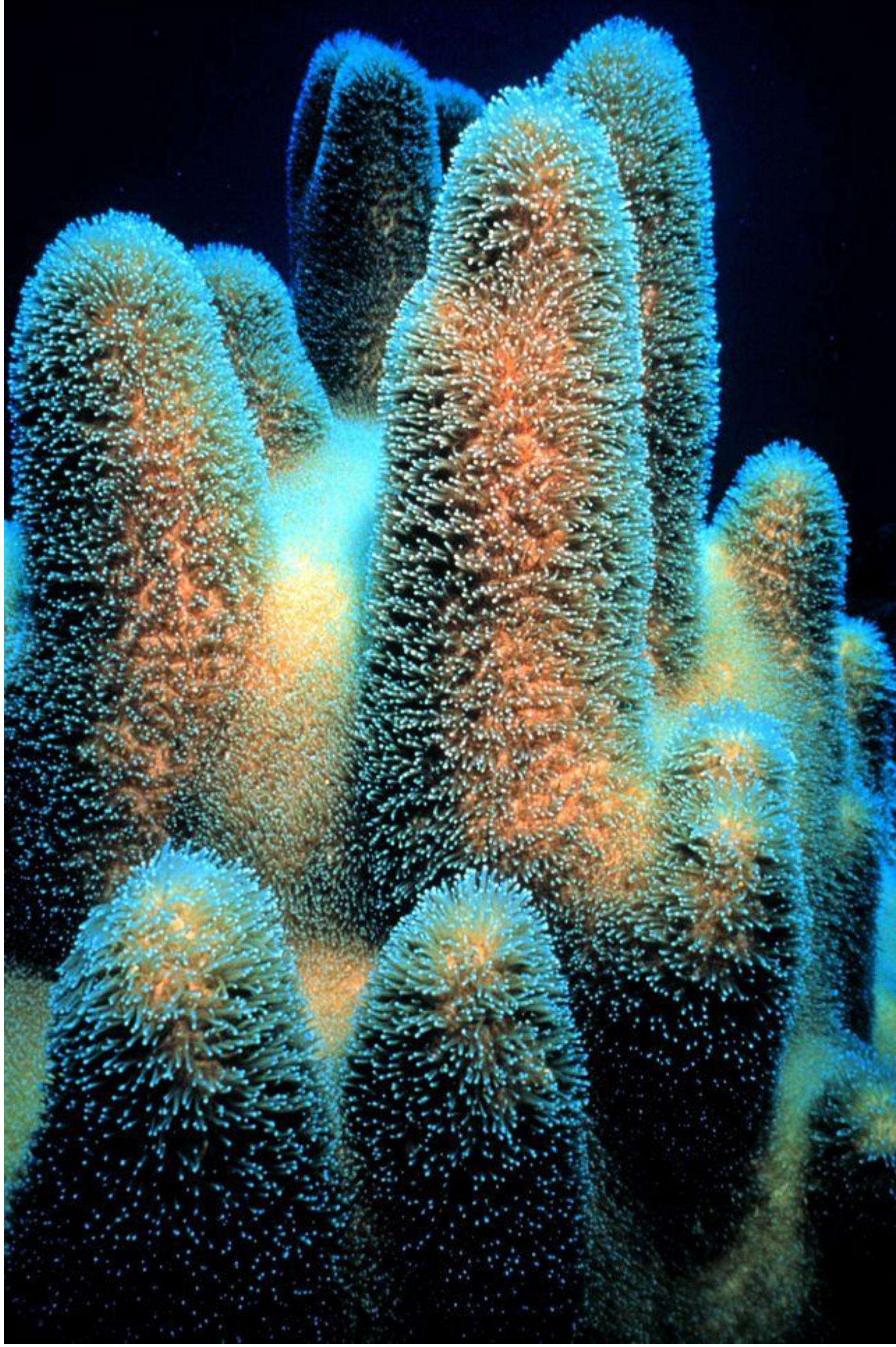
Phytoplankton (Diatoms)

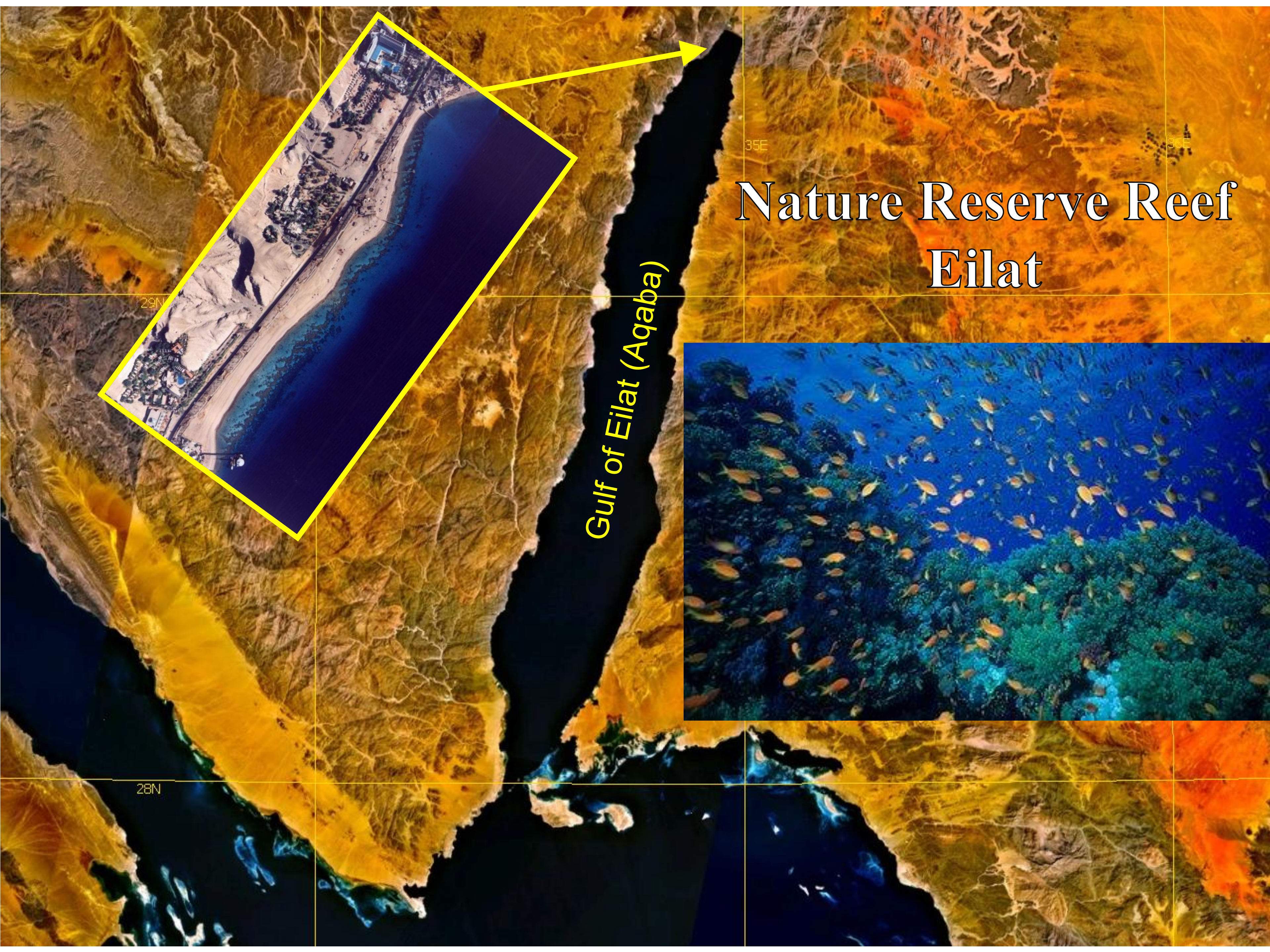


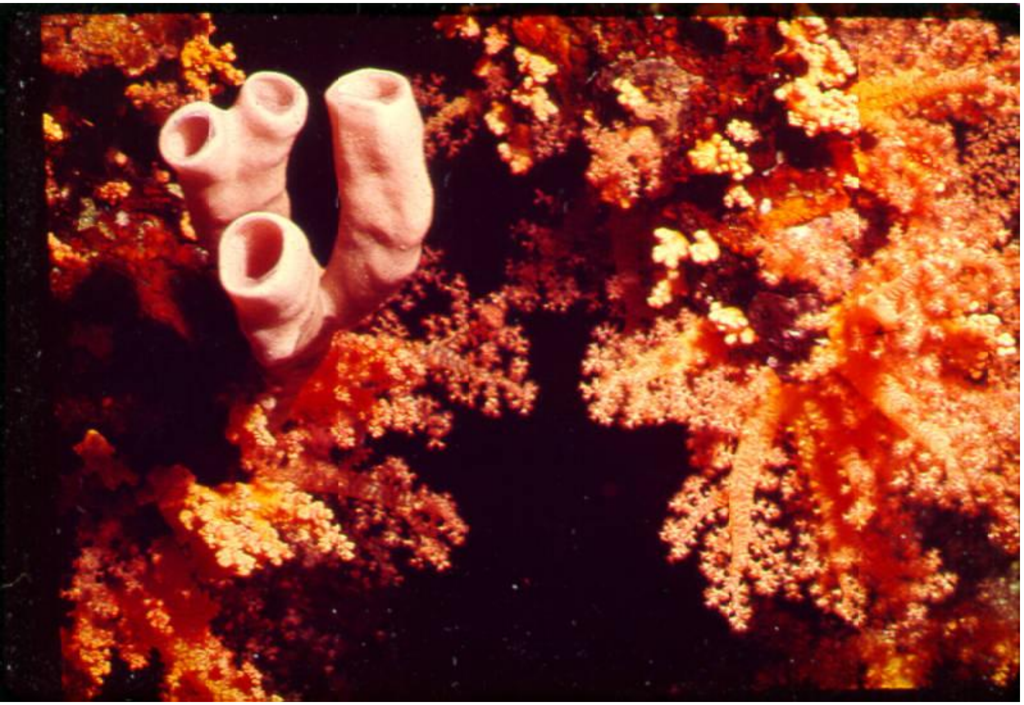
Jayne Doucette/WHOI Graphics

The coral reef is a huge filtering system for oceanic plankton

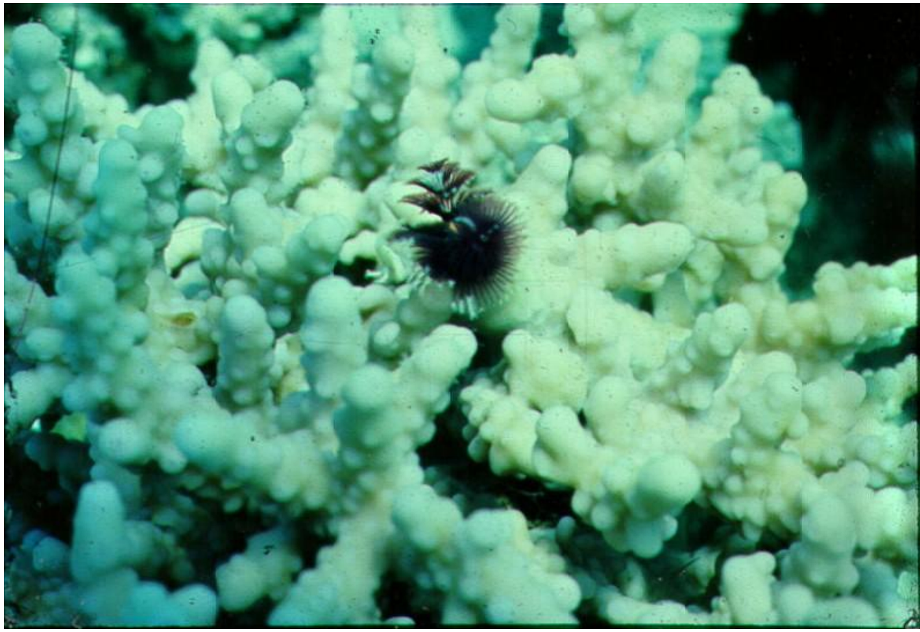
Phto: C. Verone


Nature Reserve Reef
Eilat
Gulf of Eilat (Aqaba)
35E
29N
28N



Other plankton feeders in the reef



The Modified Redfield Equation

→ *PHOTOSYNTHESIS*

$$106CO_2 + 122H_2O + 16HNO_3 + H_3PO_4 =$$

← *RESPIRATION*

Geochemical organic matter

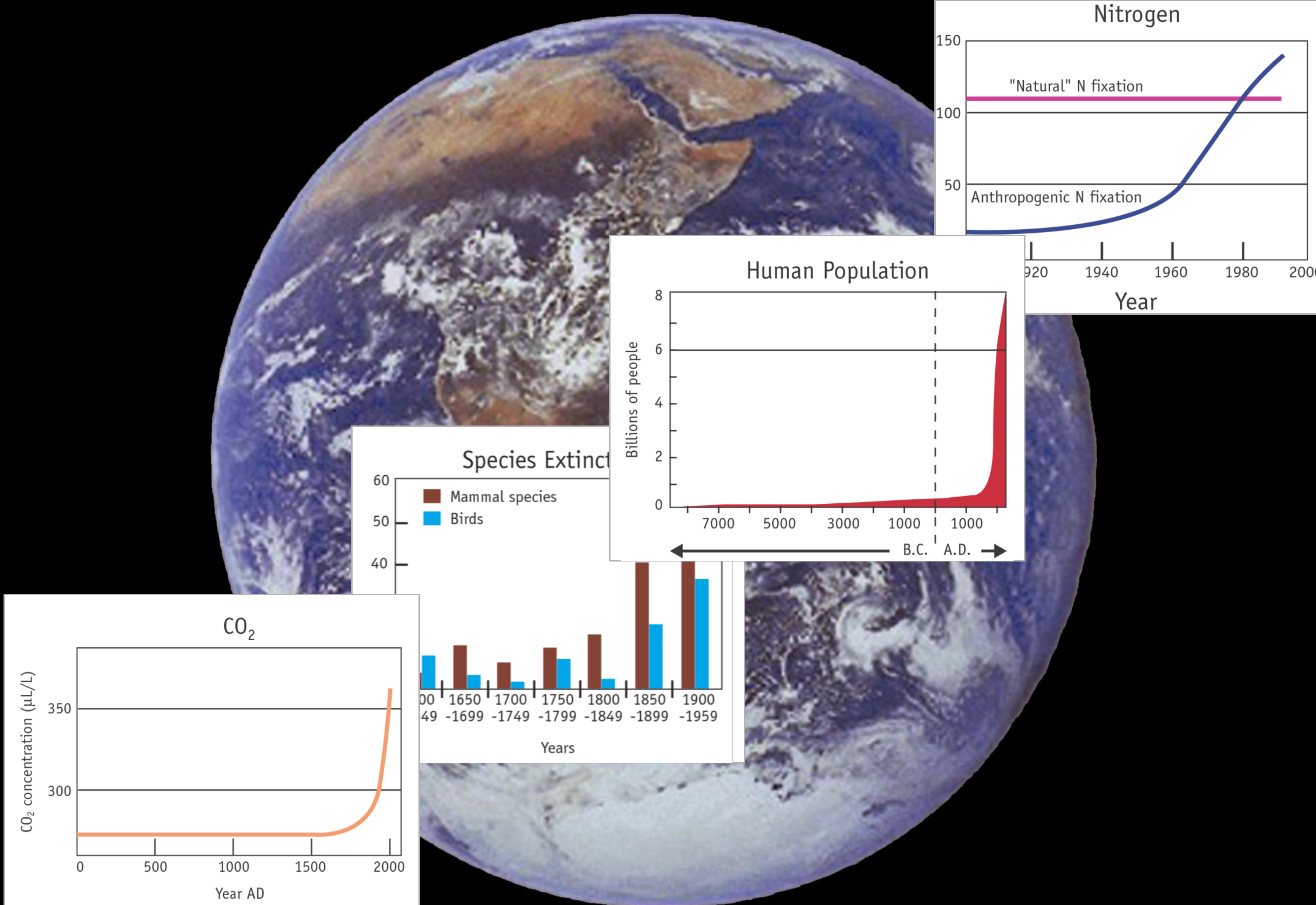
$$= (CH_2O)_{106}(NH_3)_{16}(H_3PO_4) + 138O_2$$

The key for coral reef ecosystem function is the rigid framework produced by the corals which serves are a mega-filtration system

Photo: I. Greenberg

Summary: Coral reefs, obtain their nutrients from the oceanic plankton

- Their success depends on **their solid reef framework** that allows massive bio-filtration of plankton from the intense oceanic water flows
- This requires intensive calcification by the corals and other framework builders to compensate for the bio-erosion and physical damage of storm
- *What will happen to this framework under ocean acidification?*



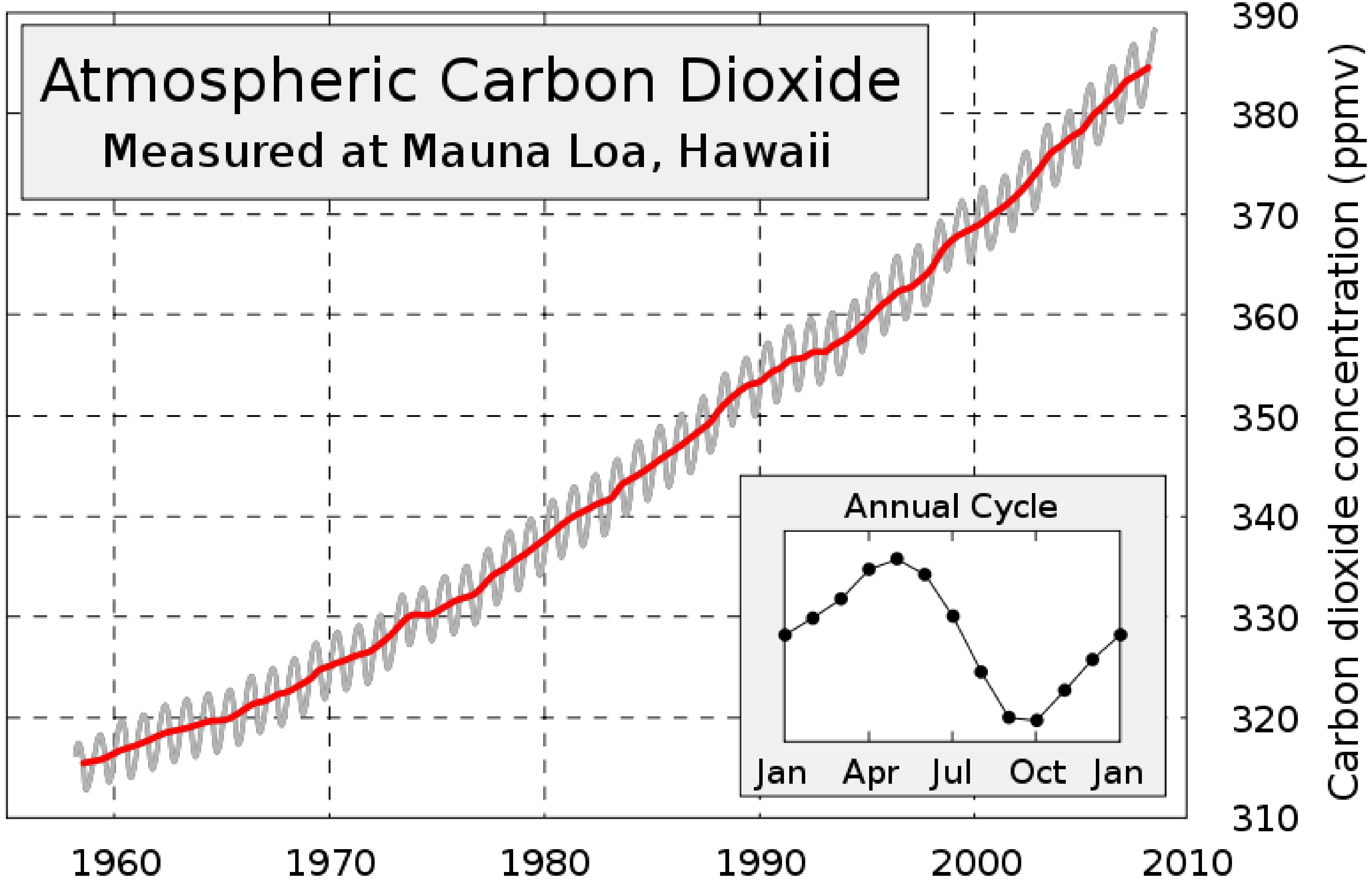
Source Moore

Influence of global change on coral reefs

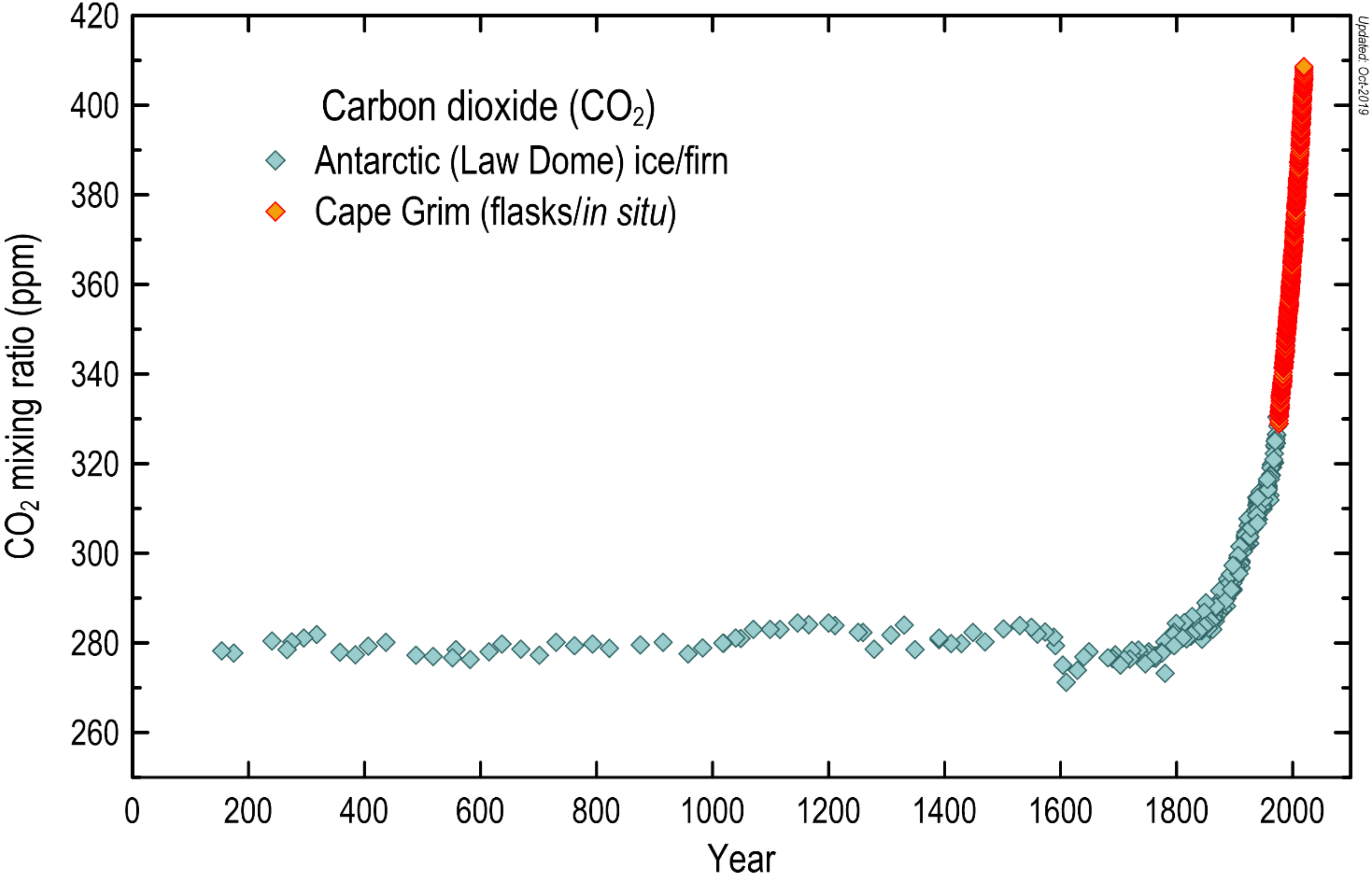
- Eutrophication from sewage and mari-culture cause algal blooms that smother the corals

- CO_2 increase lead to ocean acidification and reduced calcification of corals and others

- Global warming is causing coral bleaching and mass mortality of corals



Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii
Annual Cycle
Jan
Apr
Jul
Oct
Jan
390
380
370
360
350
340
330
320
310
Carbon dioxide concentration (ppmv)
1960
1970
1980
1990
2000
2010



Carbon dioxide (CO_2)
Antarctic (Law Dome) ice/firn
Cape Grim (flasks/*in situ*)
CO_2 mixing ratio (ppm)
Year
420
400
380
360
340
320
300
280
260
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Updated: Oct-2019

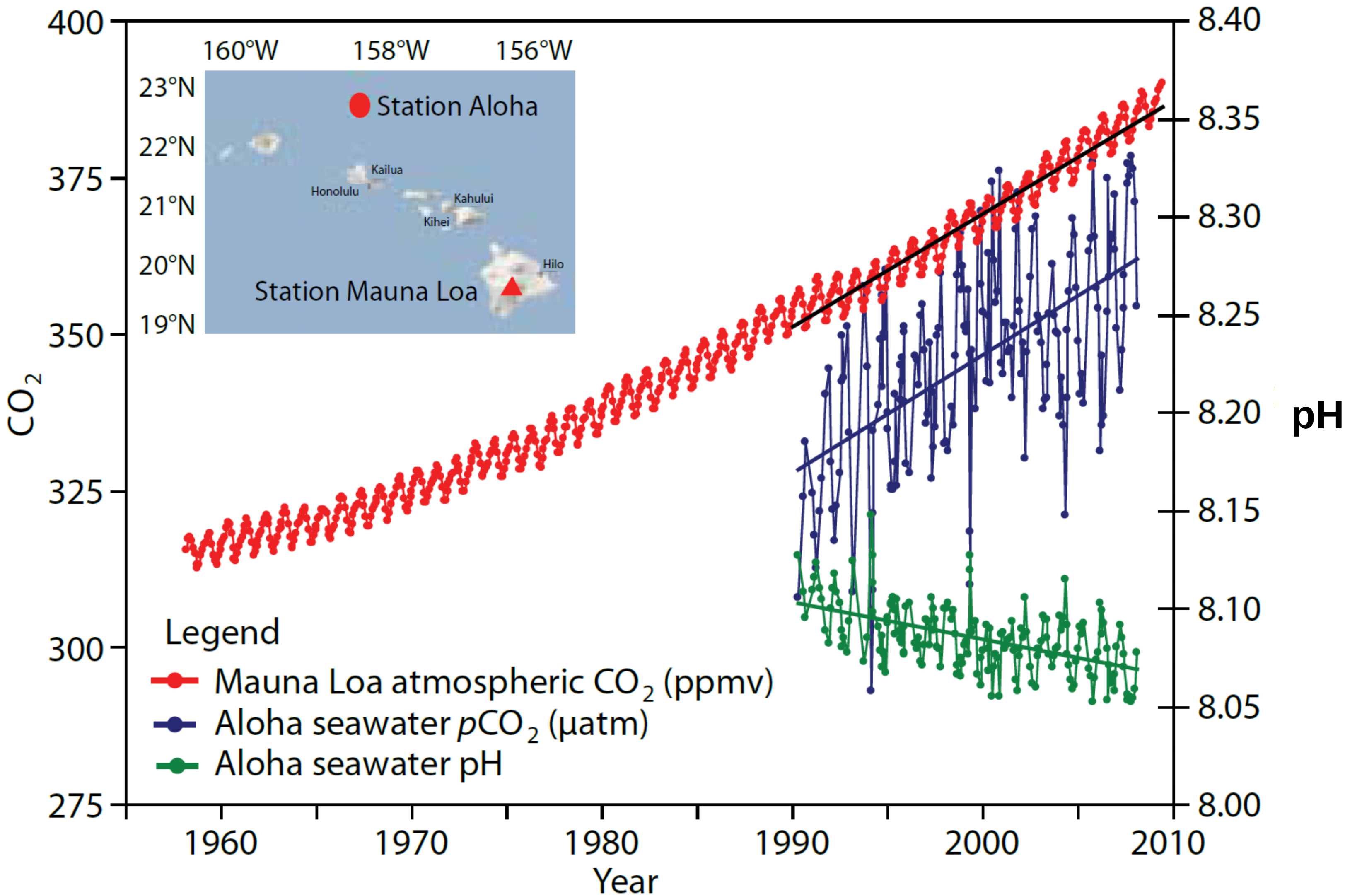
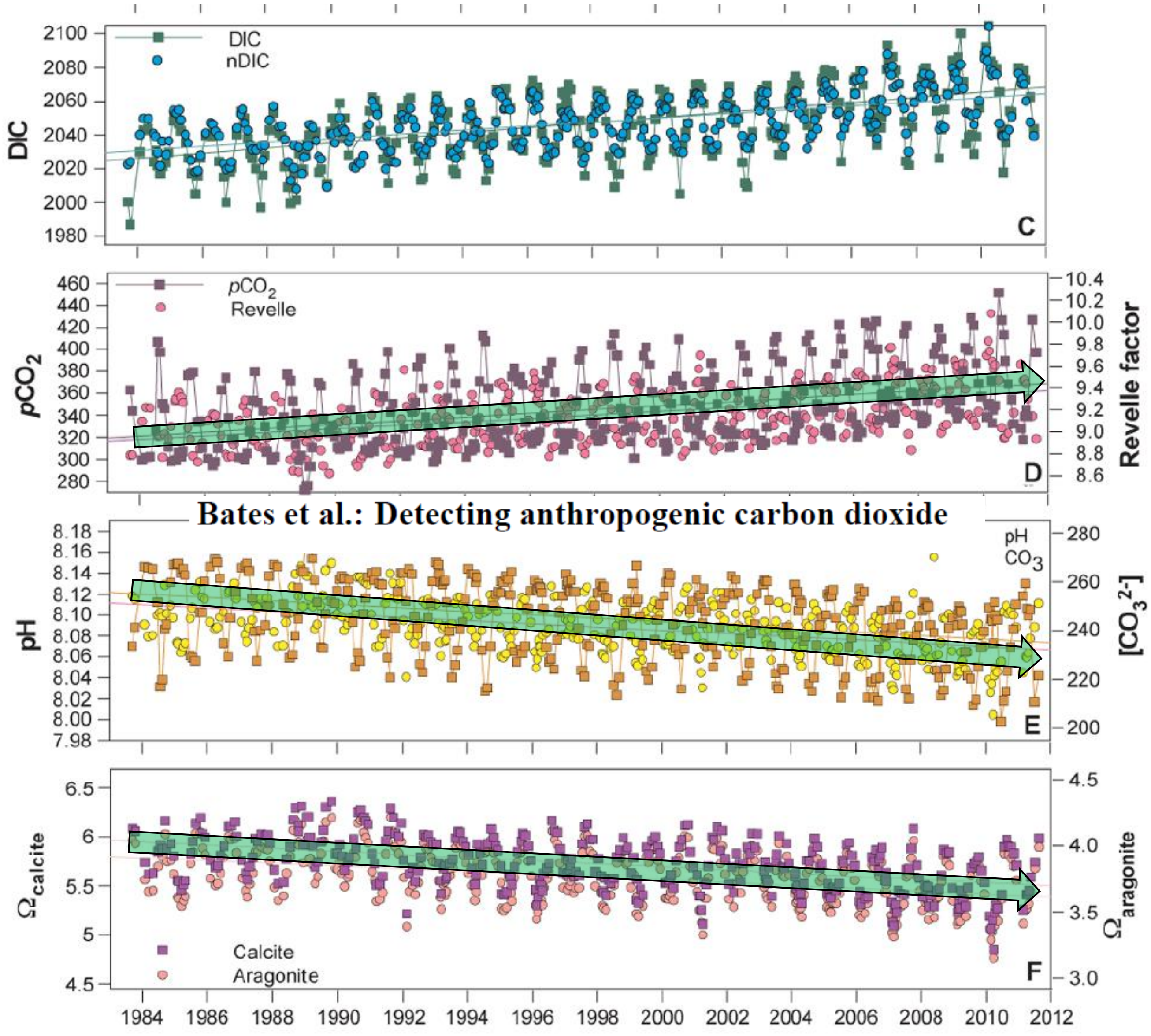


Figure 1: Time series of atmospheric CO_2 at Mauna Loa (in parts per million volume, ppmv; red), surface ocean pCO_2 (µatm; blue) and surface ocean pH (green) at Ocean Station ALOHA in the subtropical North Pacific Ocean.

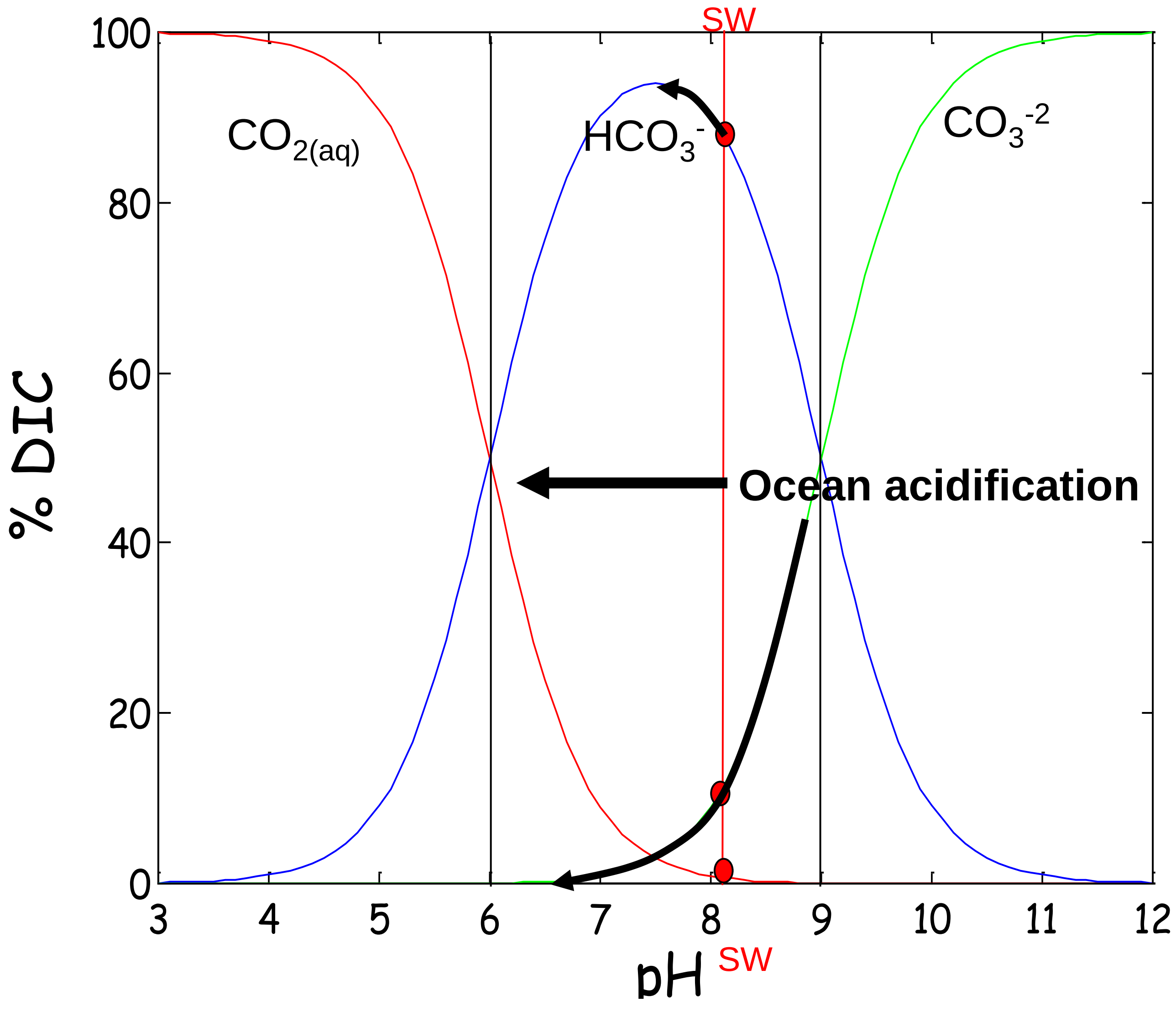
Doney et al 2009, Oceanography

BATS Bermuda Atlantic time series: 1984 - 2012



Bates et al 2013 Biogeosciences

Equilibrium of the carbonate system in the ocean



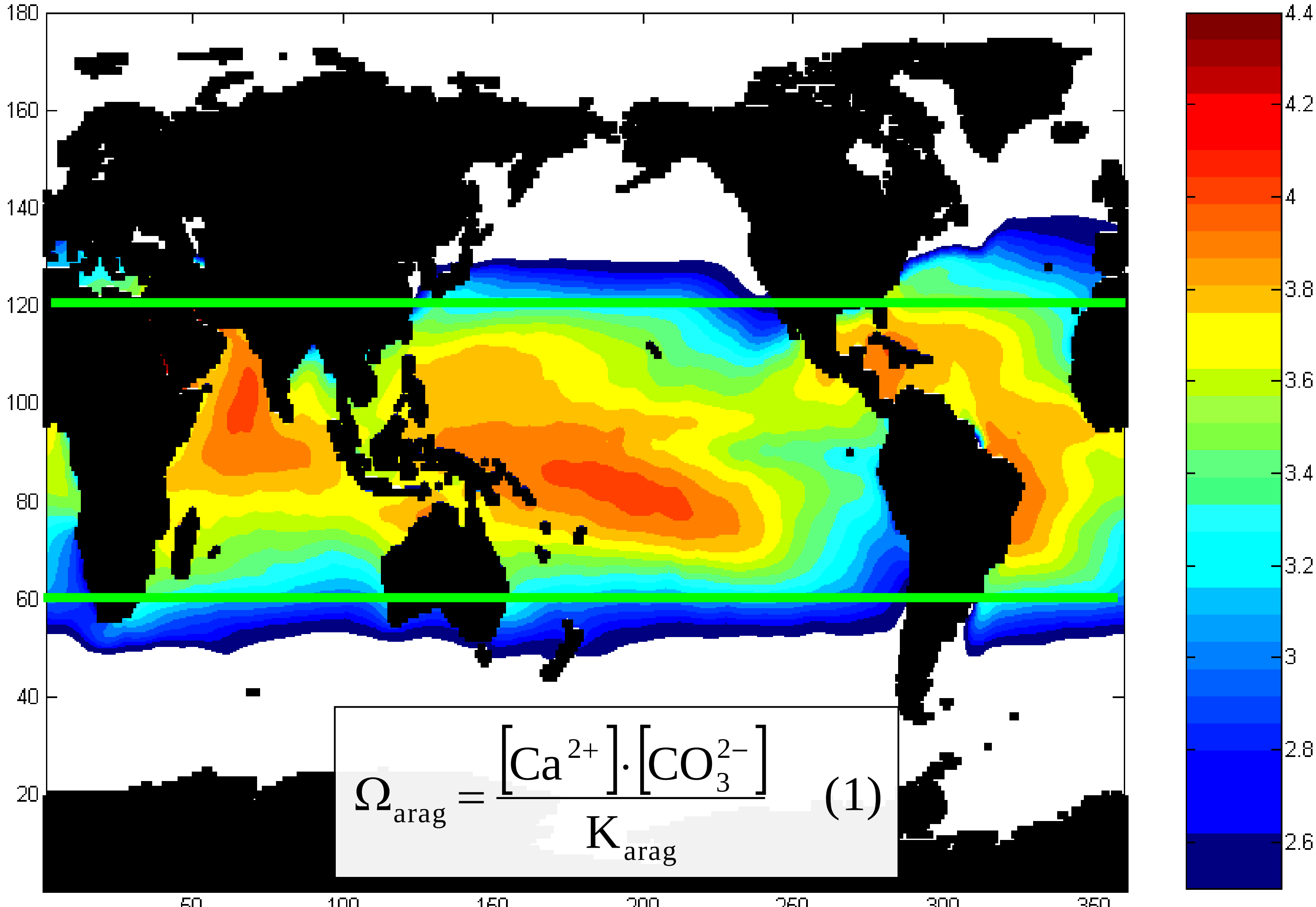
The dependence of coral calcification on $CaCO_3$ (aragonite) saturation

$$\Omega_{arag} = \frac{[Ca^{2+}]\cdot[CO_3^{2-}]}{K_{arag}} \quad (1)$$

Ca in the ocean is high (10-11 mM) and ~ constant. Therefore the CO_3^{-2} ion is controlling $\mathbf{\Omega_{arag}}$

Despite supersaturation ($\Omega_{arag} = 3\text{-}4$) reefs start to dissolve when Ω_{arag} is below 3

מידת הרוויה של מי ים ביחס לגיר שמשקיעים אלמוגים: מה שמסביר
את תפוצתם הגיאוגרפית – חרב פיפיות!

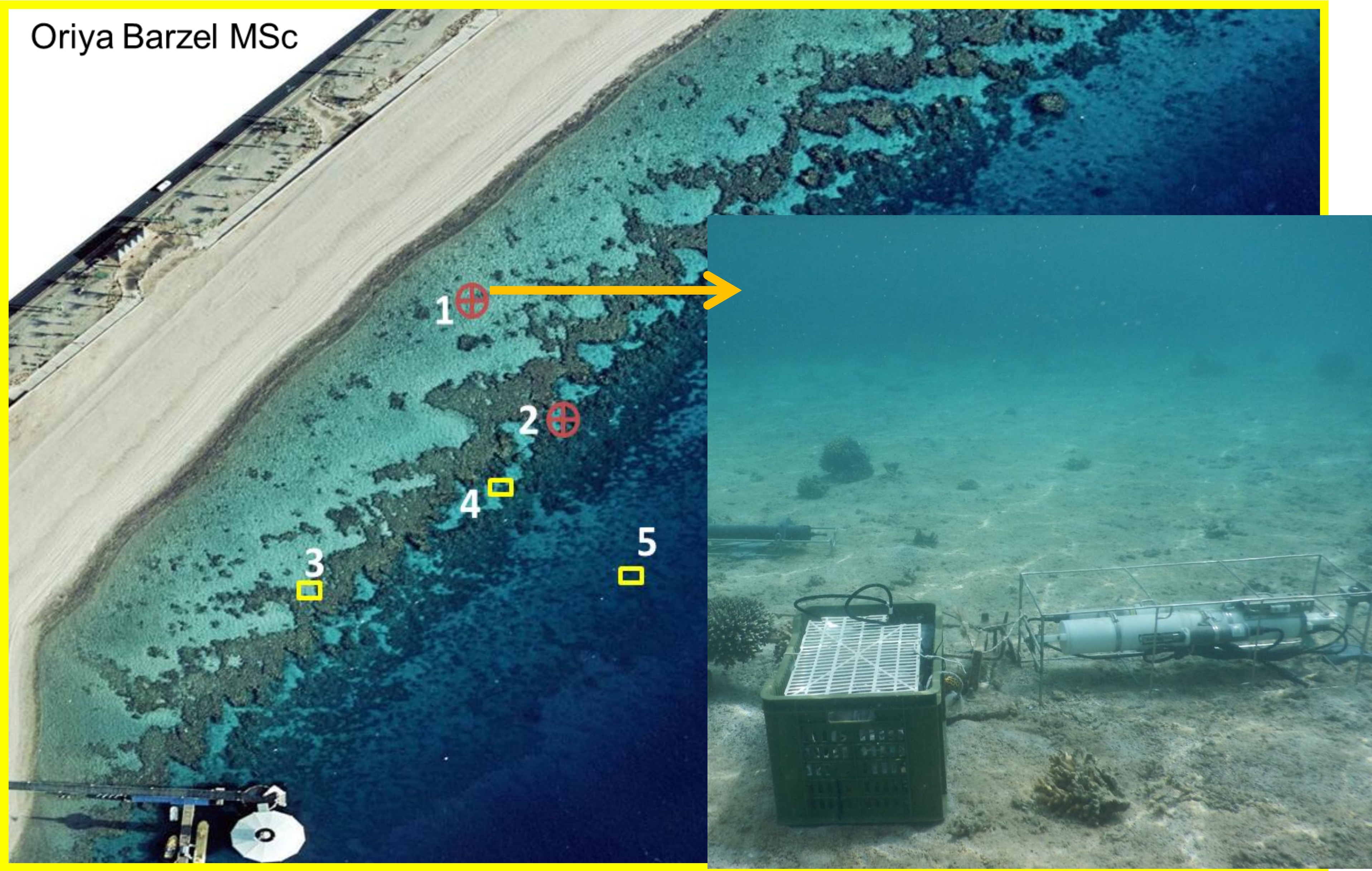


$$\Omega_{arag} = \frac{\left[Ca^{2+}\right]\cdot\left[CO_3^{2-}\right]}{K_{arag}} \qquad (1)$$

Levitus 1998

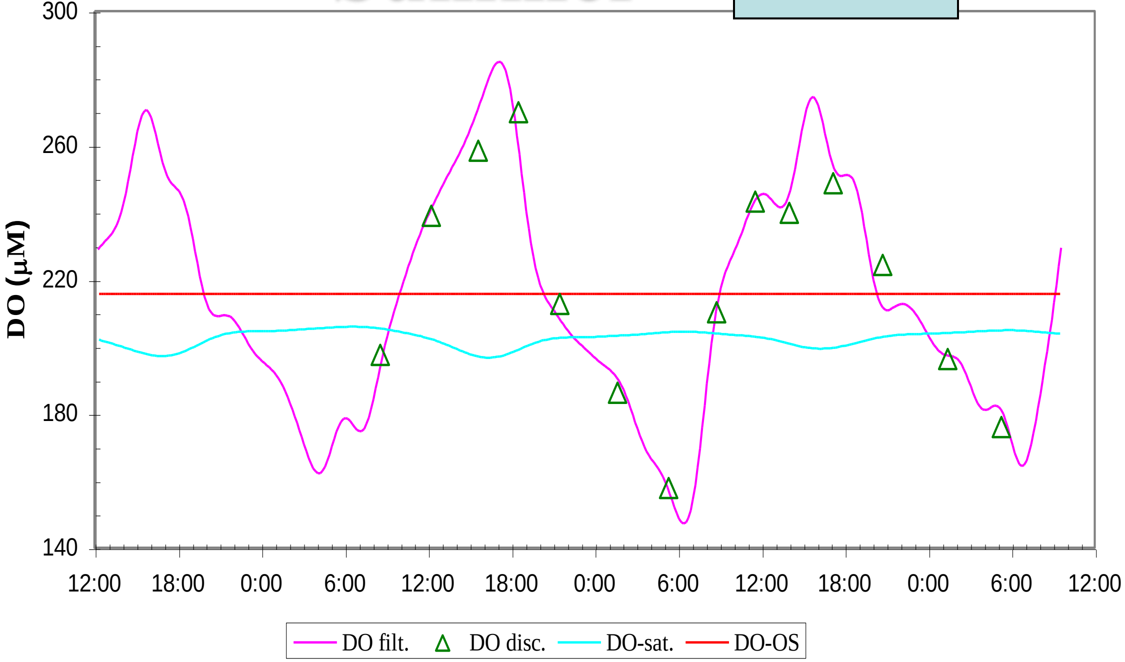
Tropical water are low in nutrients but are highly saturates for the mineral aragonite ($CaCO_3$) $\Omega_{arag.} > 3.5$

Community metabolism in the Eilat reef

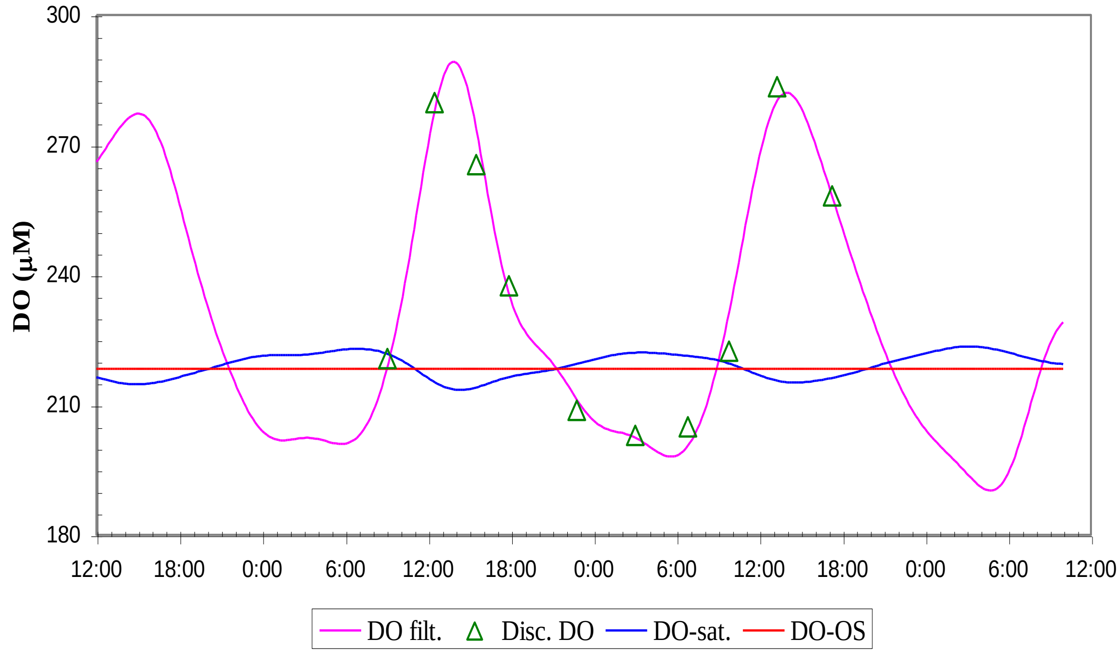


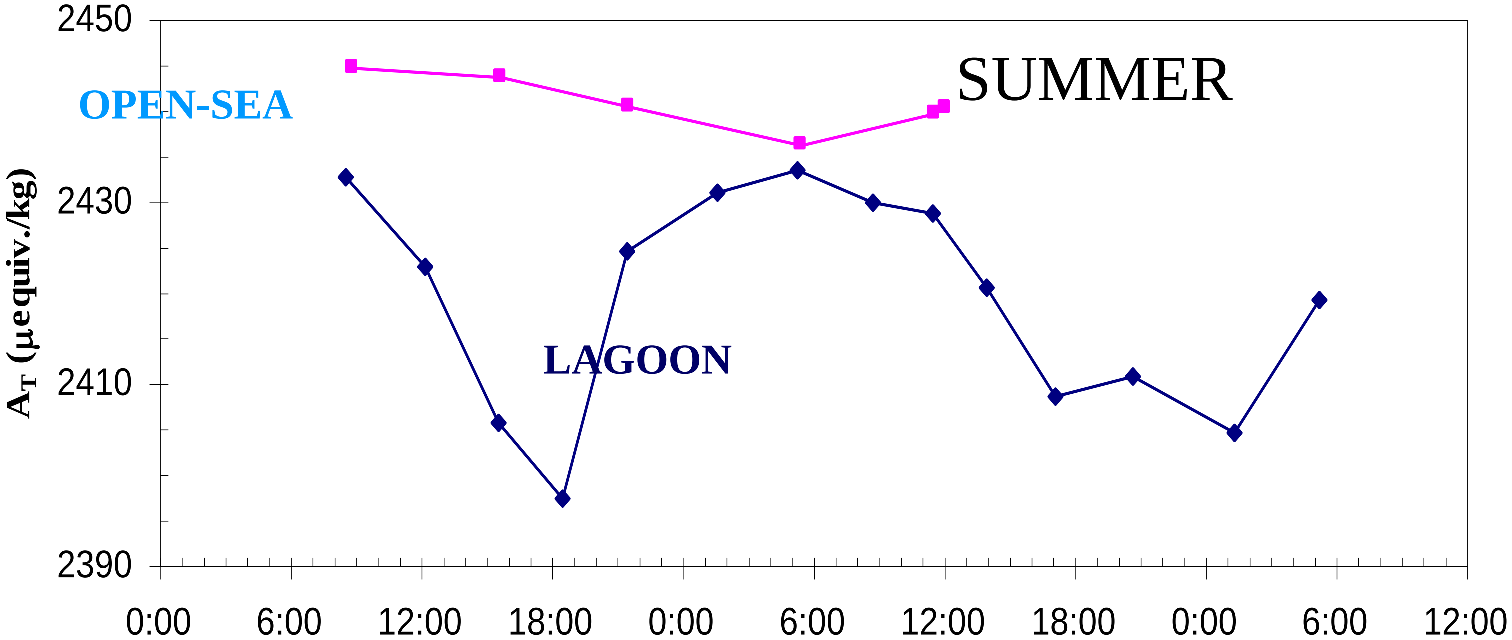
Photosynthesis and respiration

Summer P/R≅1

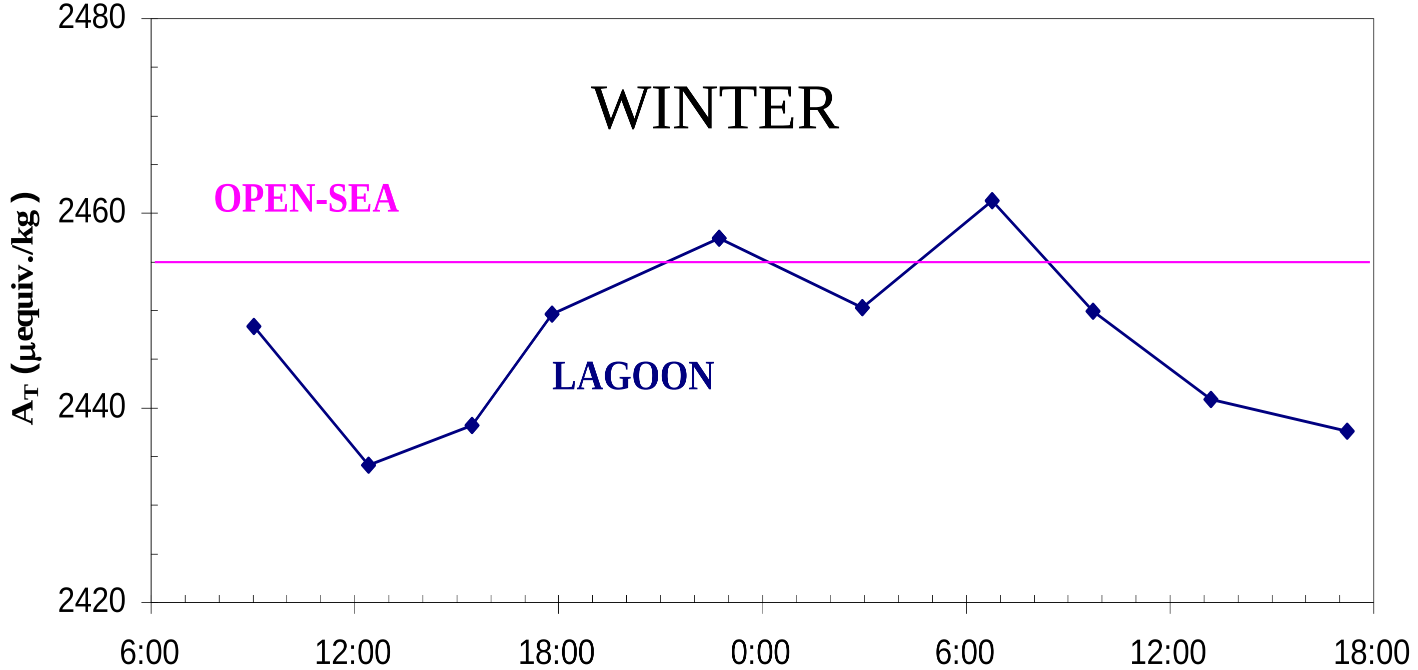


Winter P/R≅1.5

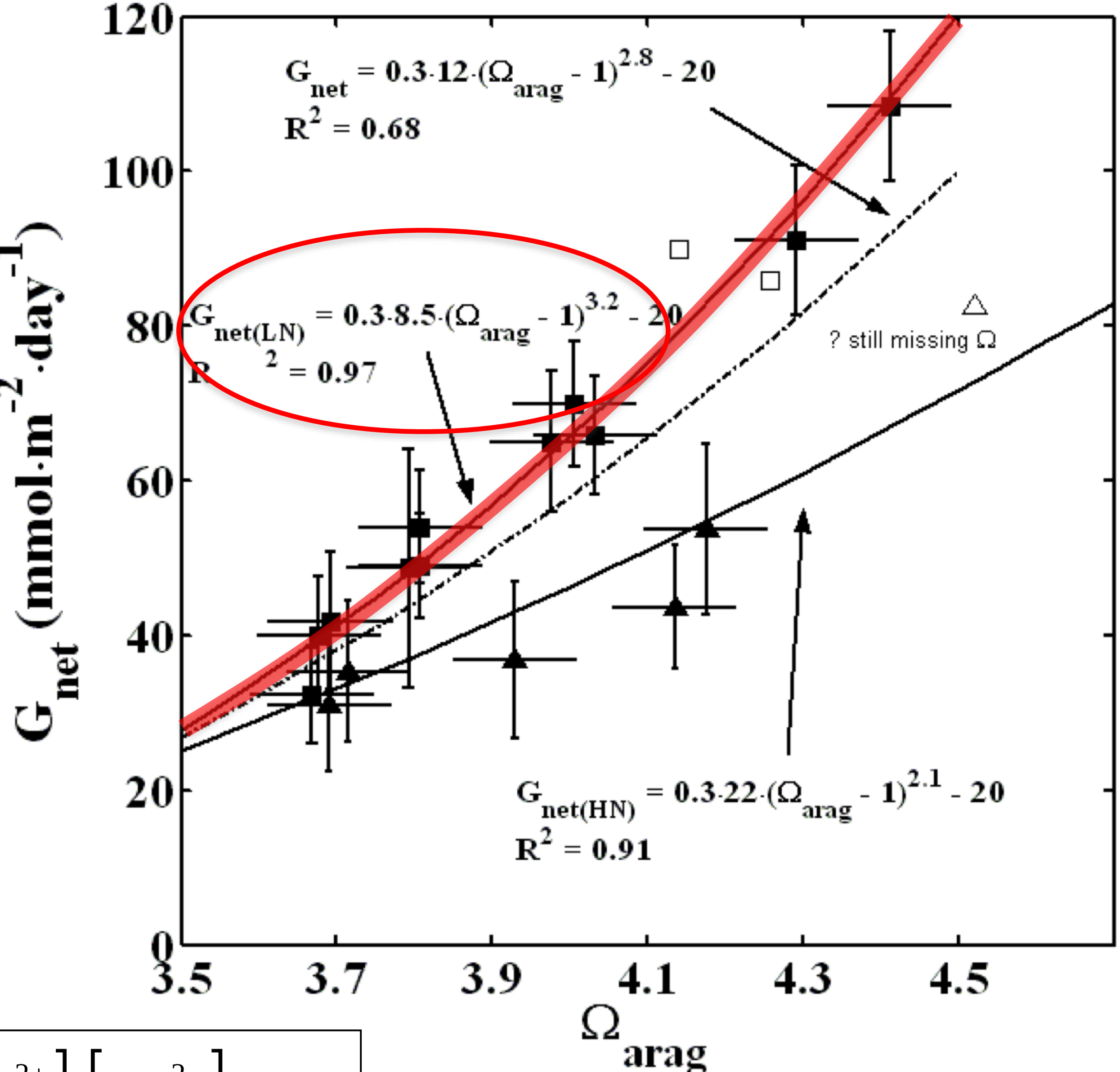




Calcification



Eilat reef calcification

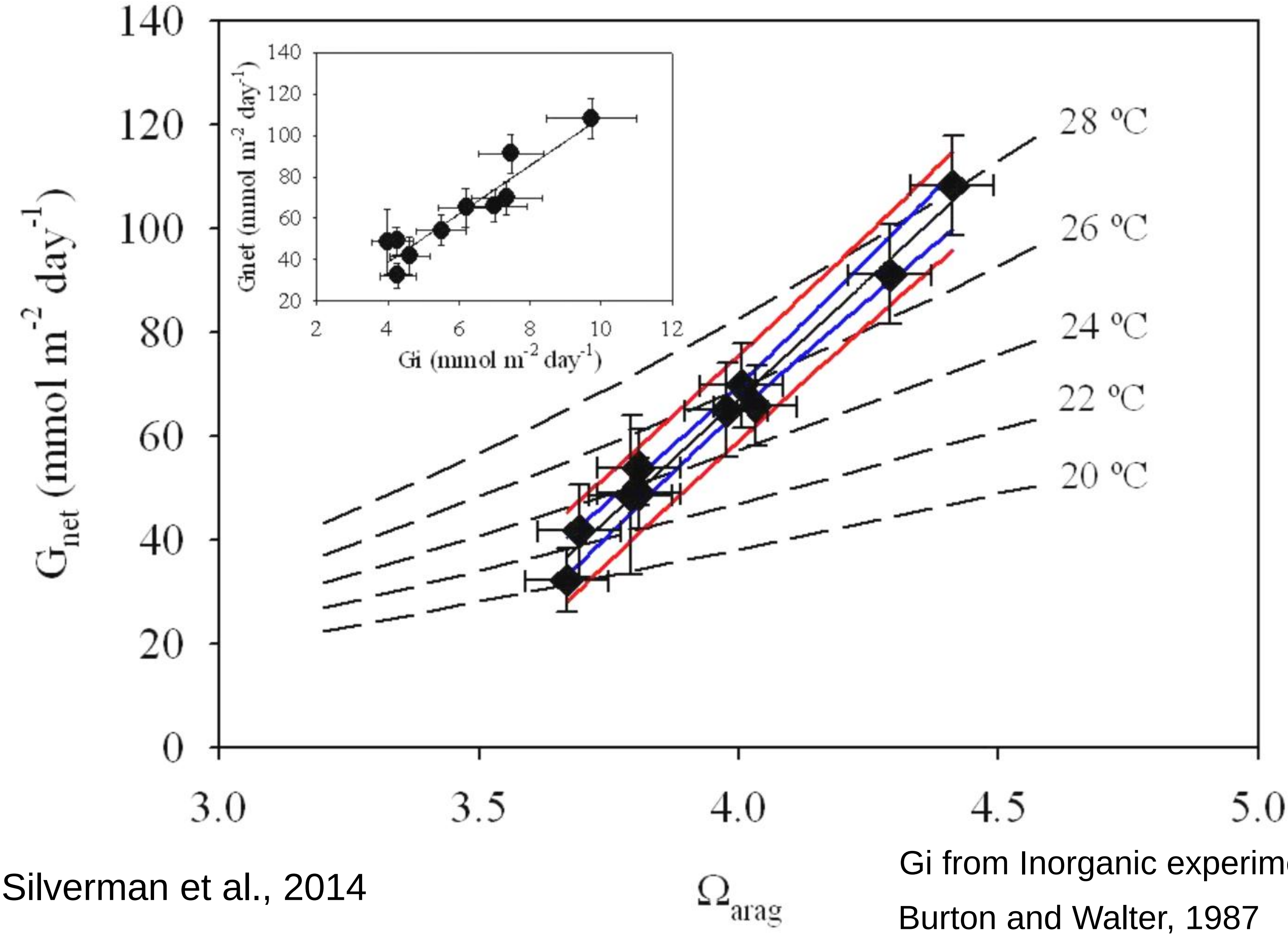


Jacob Silverman PhD Thesis

$$\Omega_{arag} = \frac{[Ca^{2+}] \cdot [CO_3^{2-}]}{K_{arag}} \quad (1)$$

Silverman *et al*, 2007

Eilat reef calcification as a function of Ω



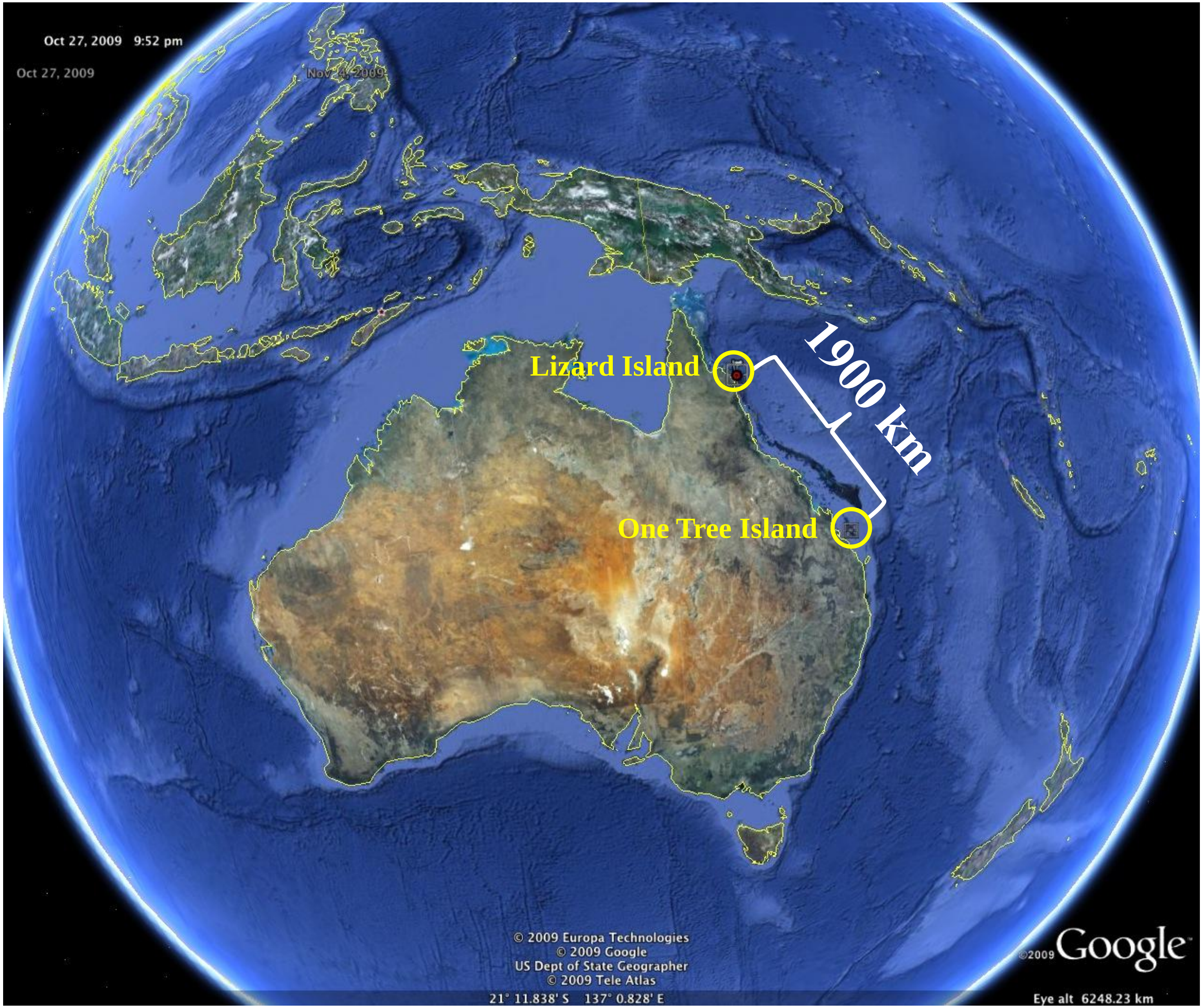
Silverman et al., 2014

Gi from Inorganic experiments

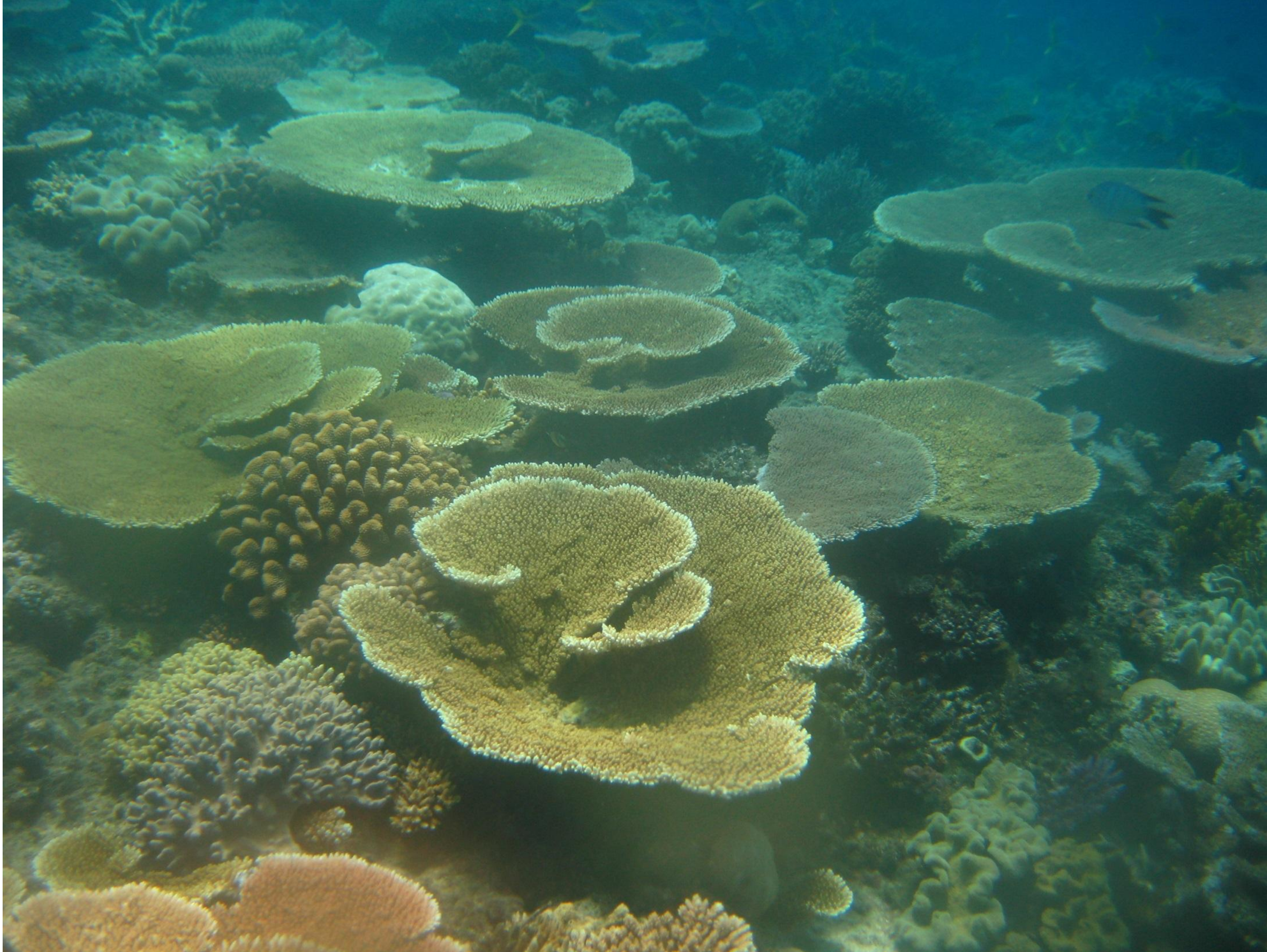
Burton and Walter, 1987

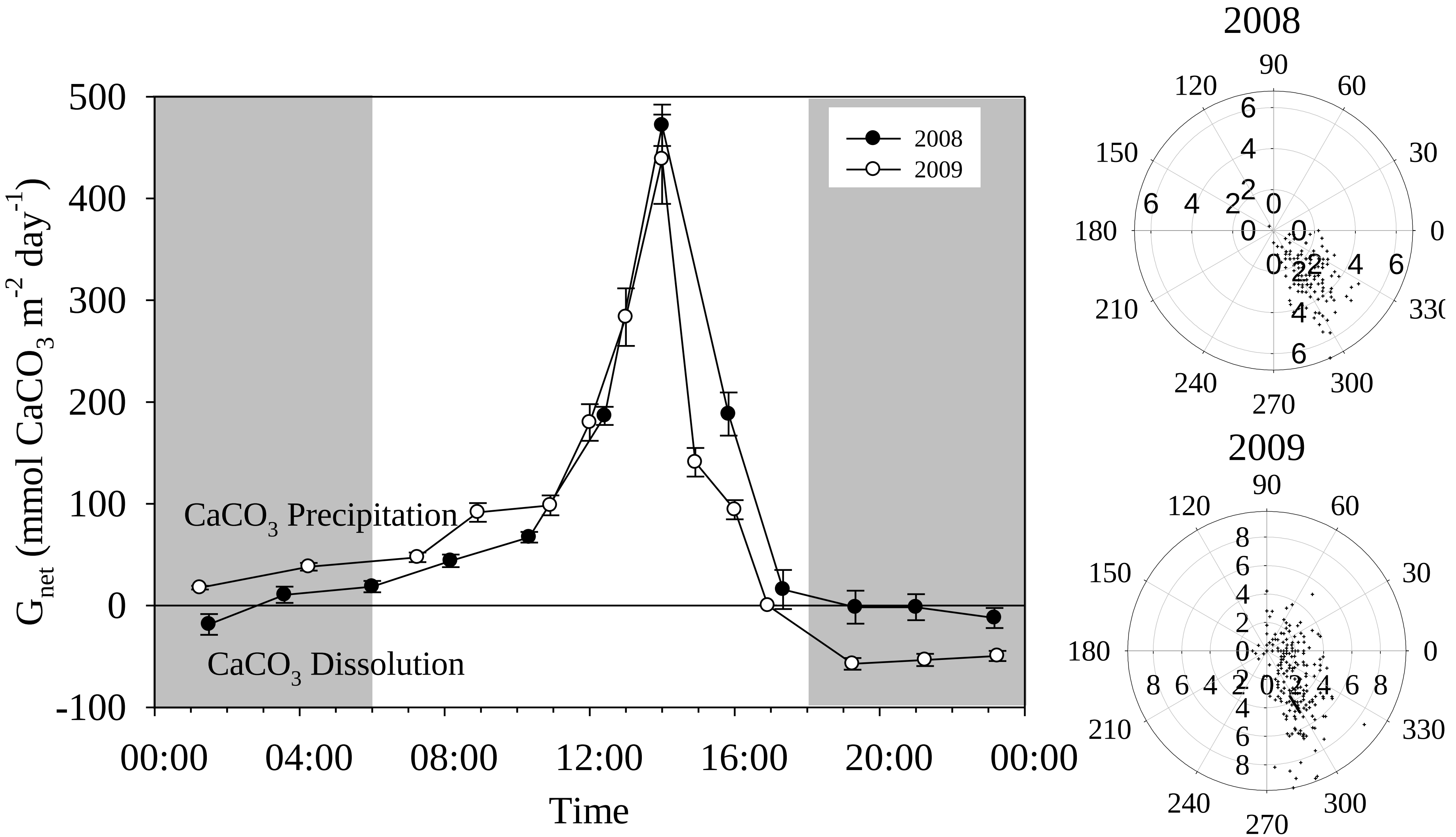
The global picture

Photo: I. Greenberg



Oct 27, 2009 9:52 pm
Oct 27, 2009
Nov 4, 2009
Lizard Island
1900 km
One Tree Island
© 2009 Europa Technologies
© 2009 Google
US Dept of State Geographer
© 2009 Tele Atlas
21° 11.838' S 137° 0.828' E
©2009 Google
Eye alt 6248.23 km

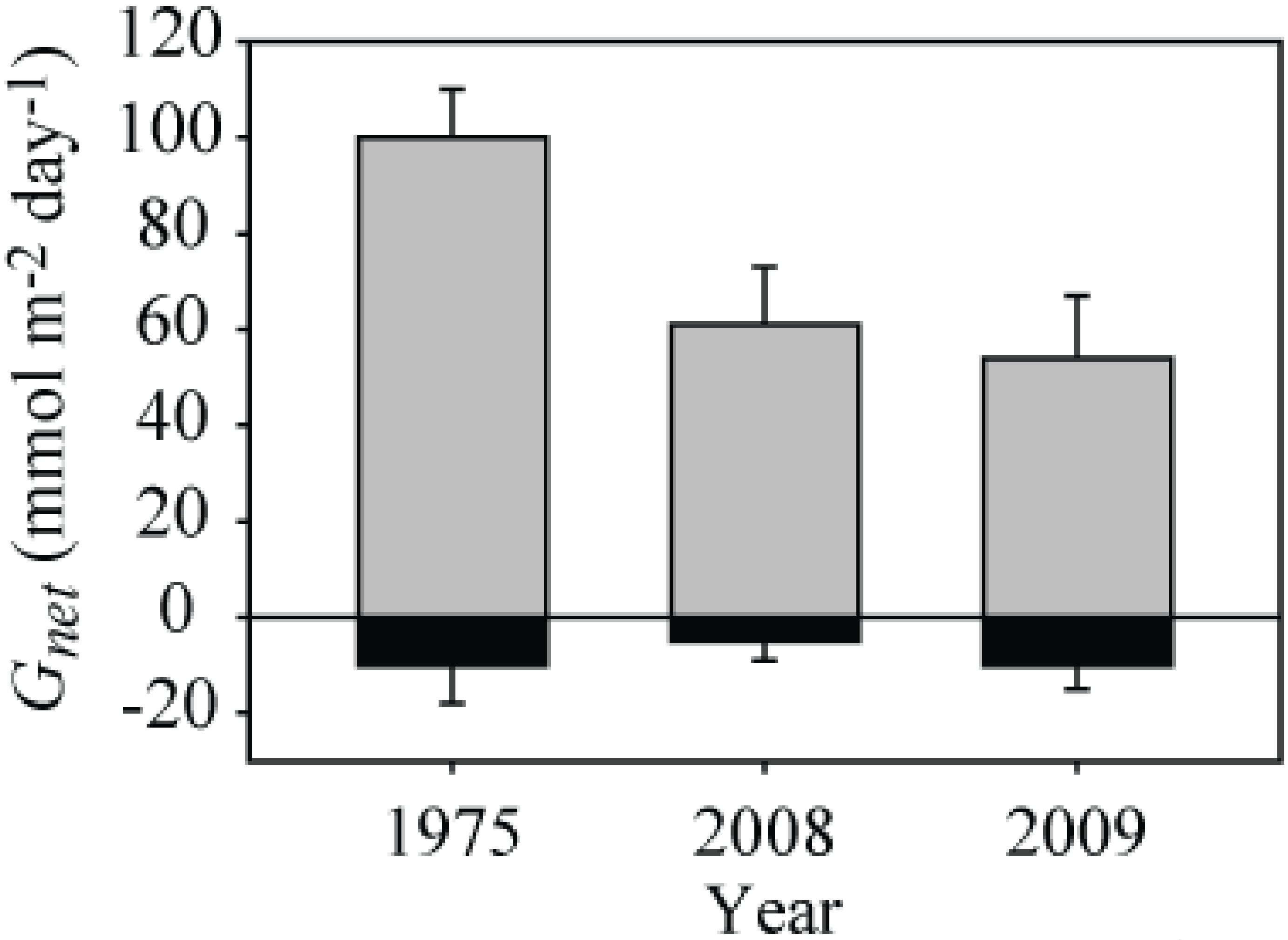




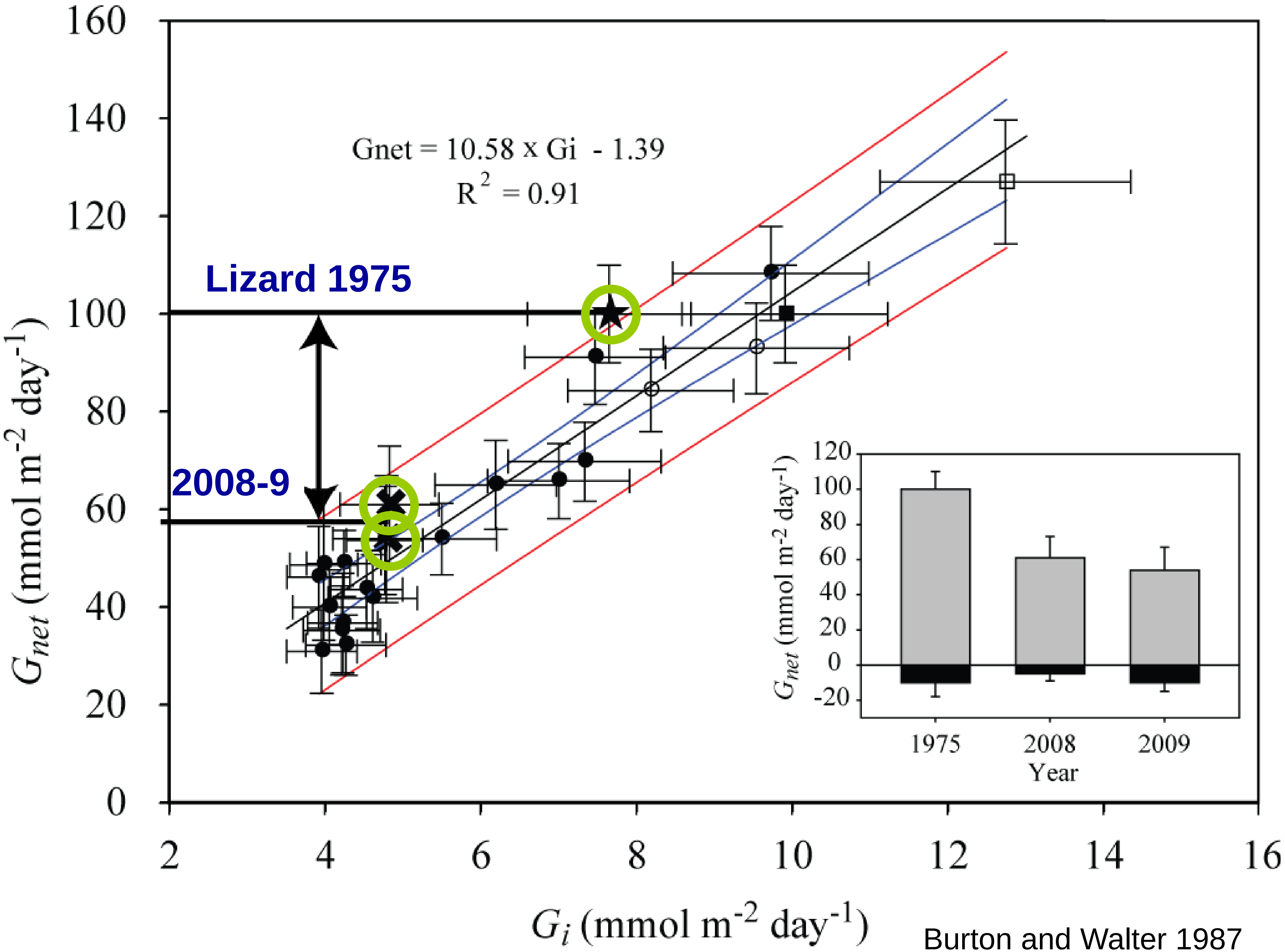
2008
2009
Gnet (mmol CaCO3 m-2 day-1)
500
400
300
200
100
0
-100
CaCO3 Precipitation
CaCO3 Dissolution
00:00
04:00
08:00
12:00
16:00
20:00
00:00
Time
90
120
60
150
30
180
0
210
330
240
300
270

GBR expedition (HUJI –Stanford)

Intensive work in the 1970s by Barnes and Kinsey



pCO_2= 330 **pCO_2= 390**

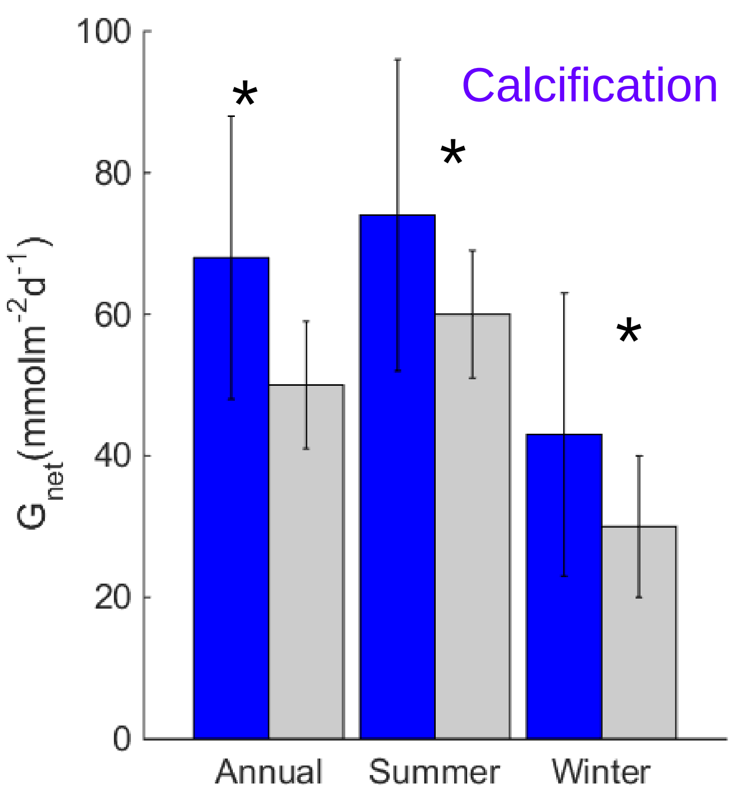


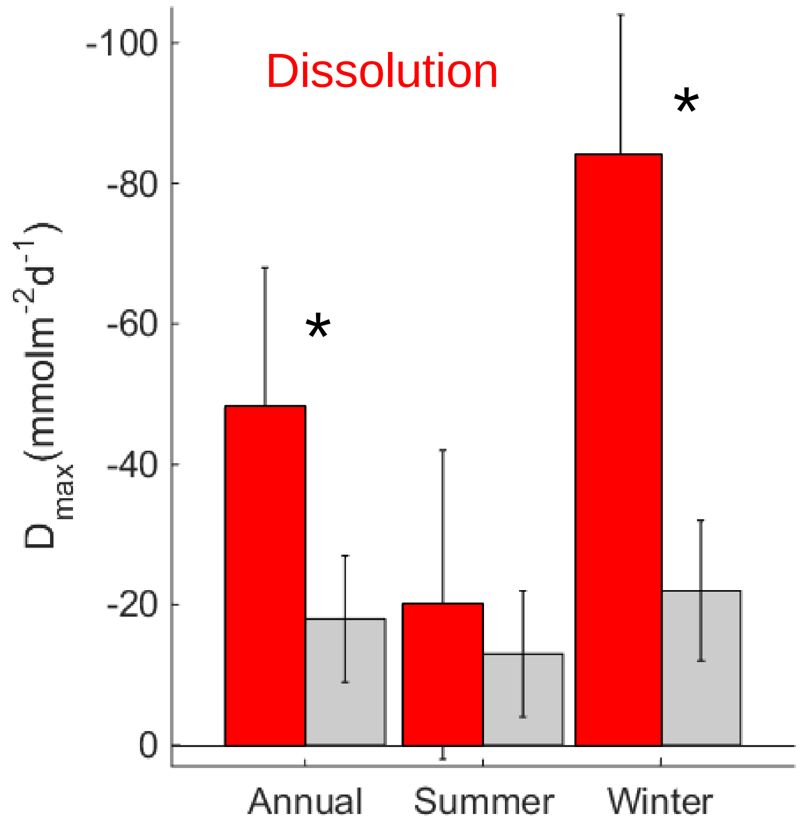
Burton and Walter 1987

Barzel and Silverman

Eilat: 15 years perspective

Calcification and Dissolution 2015-6 vs. 2000-2





10-15 % increase in live cover

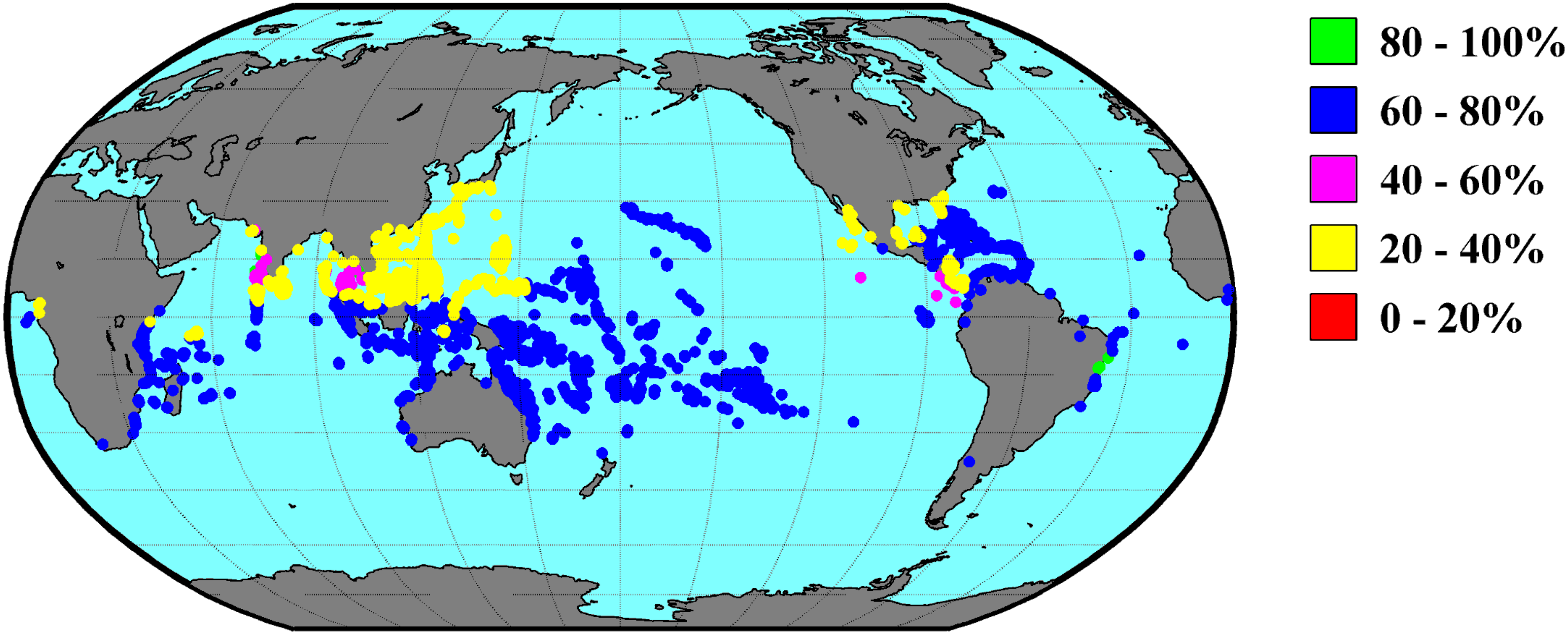
* $p<0.05$

38 ppm increase in atmospheric CO_2


#OceanAcidification is the
osteoporosis
of the sea.


- Jane Lubchenco
Administrator, National Oceanic and Atmospheric Administration

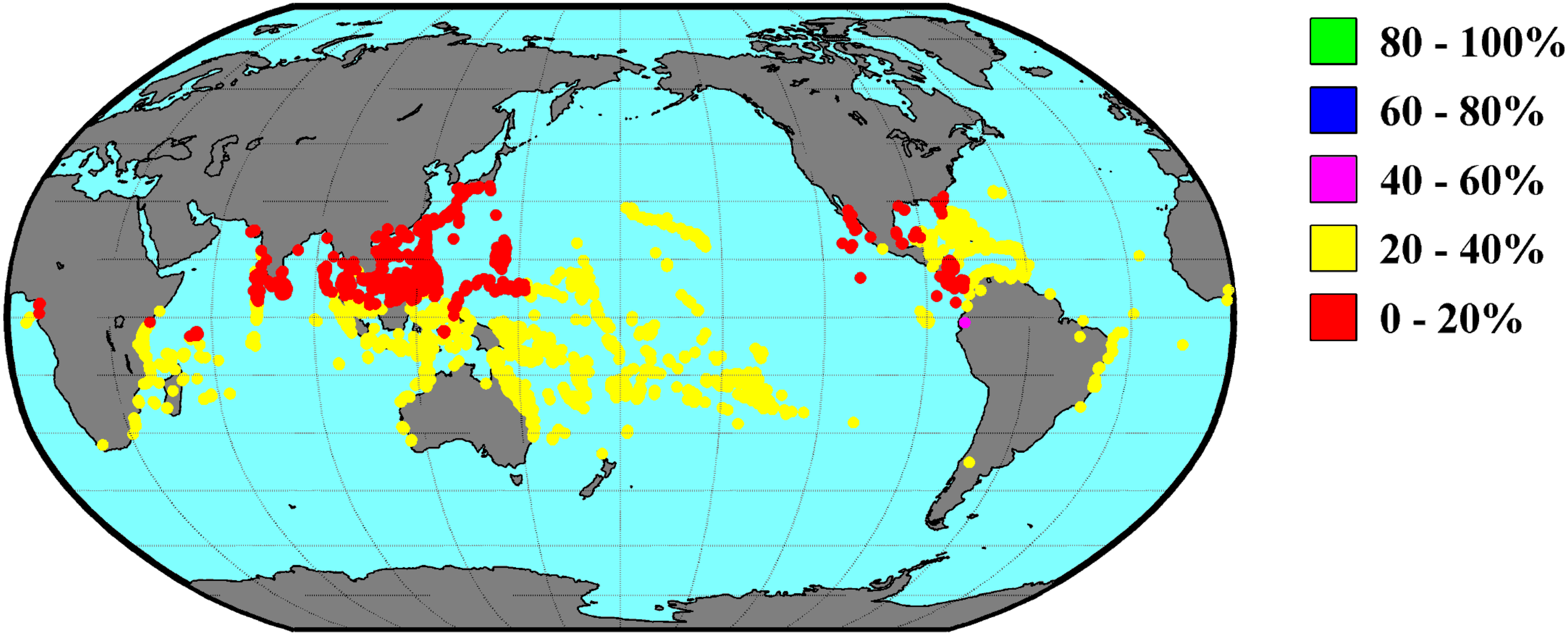
pCO_2 = 380 ppm, A_c modified by bleaching



Calculated from the Eilat reef data relative the preindustrial conditions
(280 ppm)

Silverman et al., 2009 GRL

pCO_2 = 450 ppm, A_c modified by bleaching

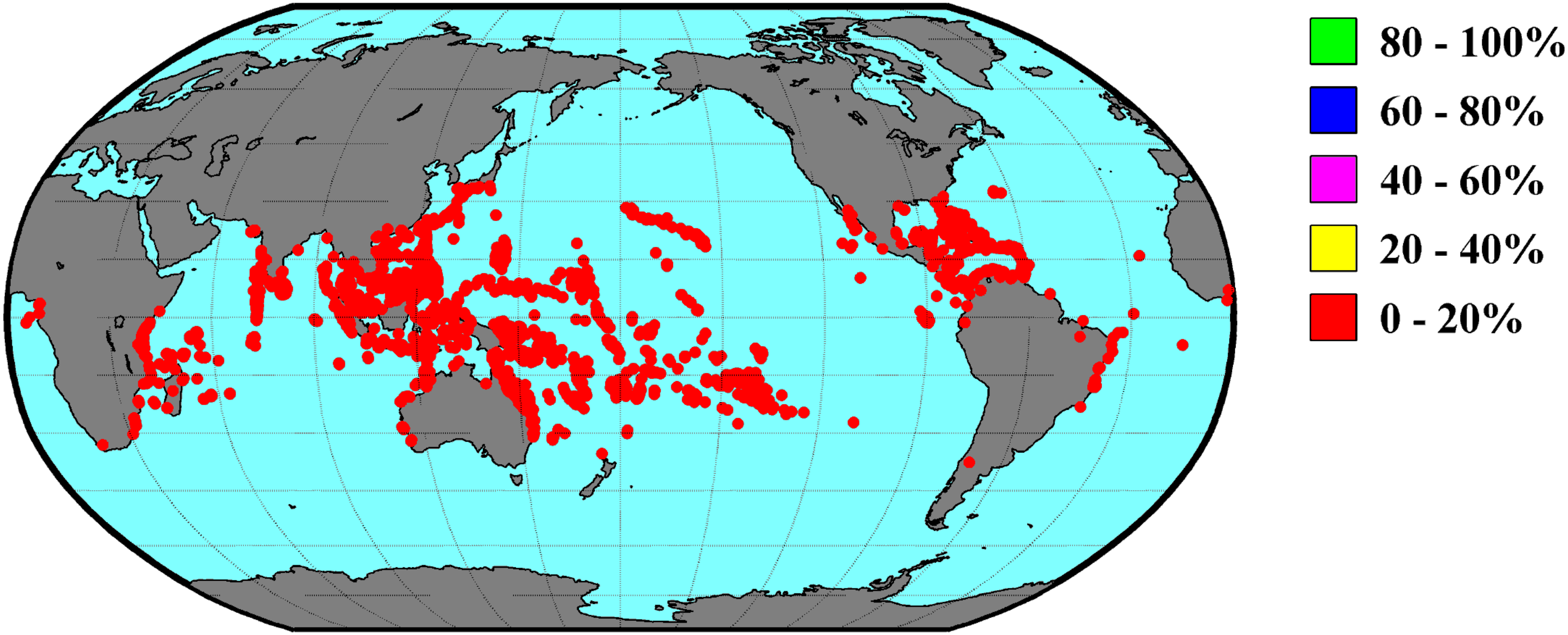


Calculated from the Eilat reef data relative the preindustrial conditions

(280 ppm)

Silverman et al., 2009 GRL

pCO_2 = 560 ppm, A_c modified by bleaching



Calculated from the Eilat reef data relative the preindustrial conditions

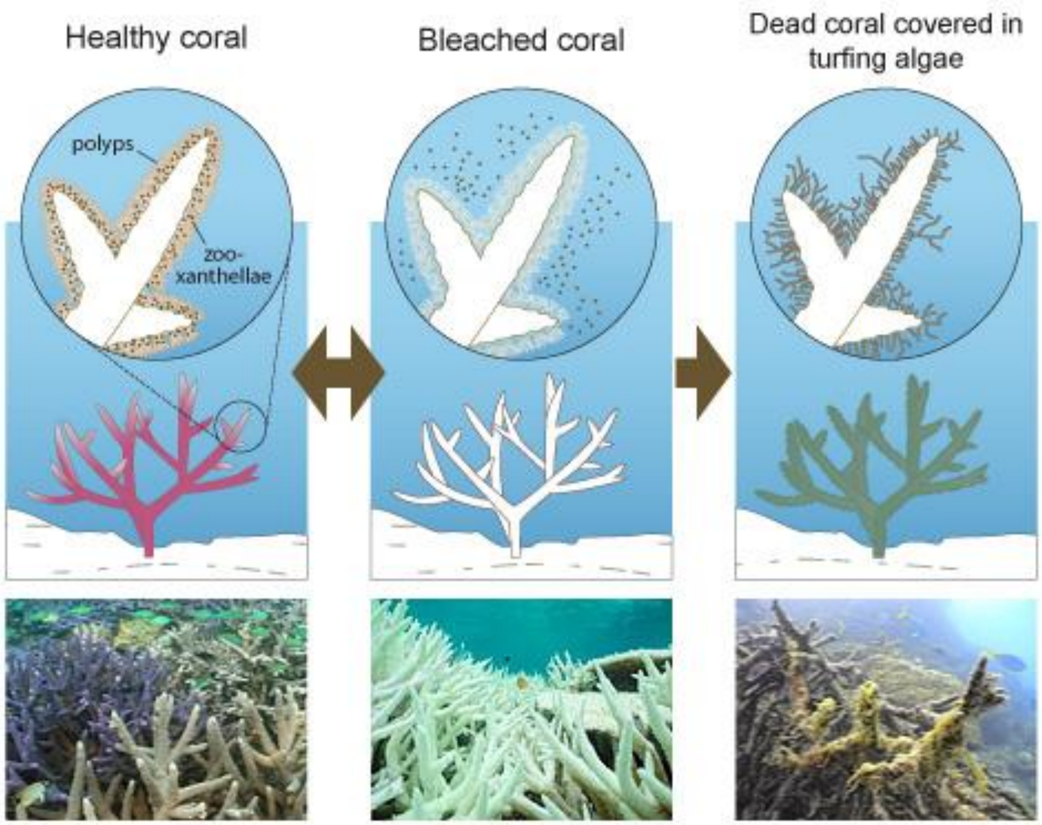
(280 ppm)

Silverman et al., 2009 GRL

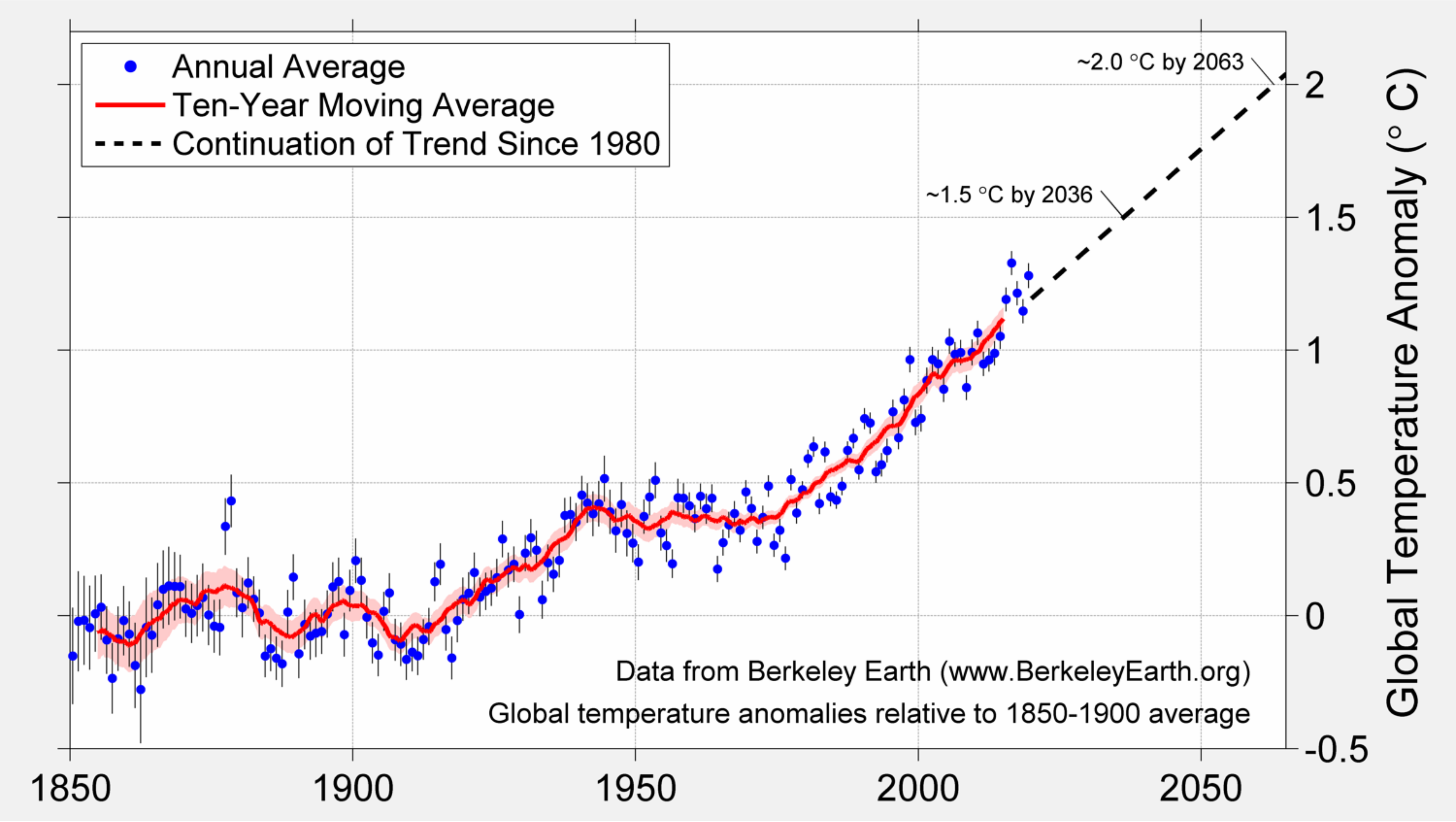
Coral bleaching

- When temperatures go up ~ 1-2 ^{o}C above the summer maximum for a more than a week coral bleach
- The symbionts are expelled from the coral and it looses its pigments becoming bright white
- In most cases the corals die and small reef are turned into rubble
- Bleaching started in 1982 and now it occurs almost every year
- More than 50% of the world corals have died from bleaching already

Coral bleaching

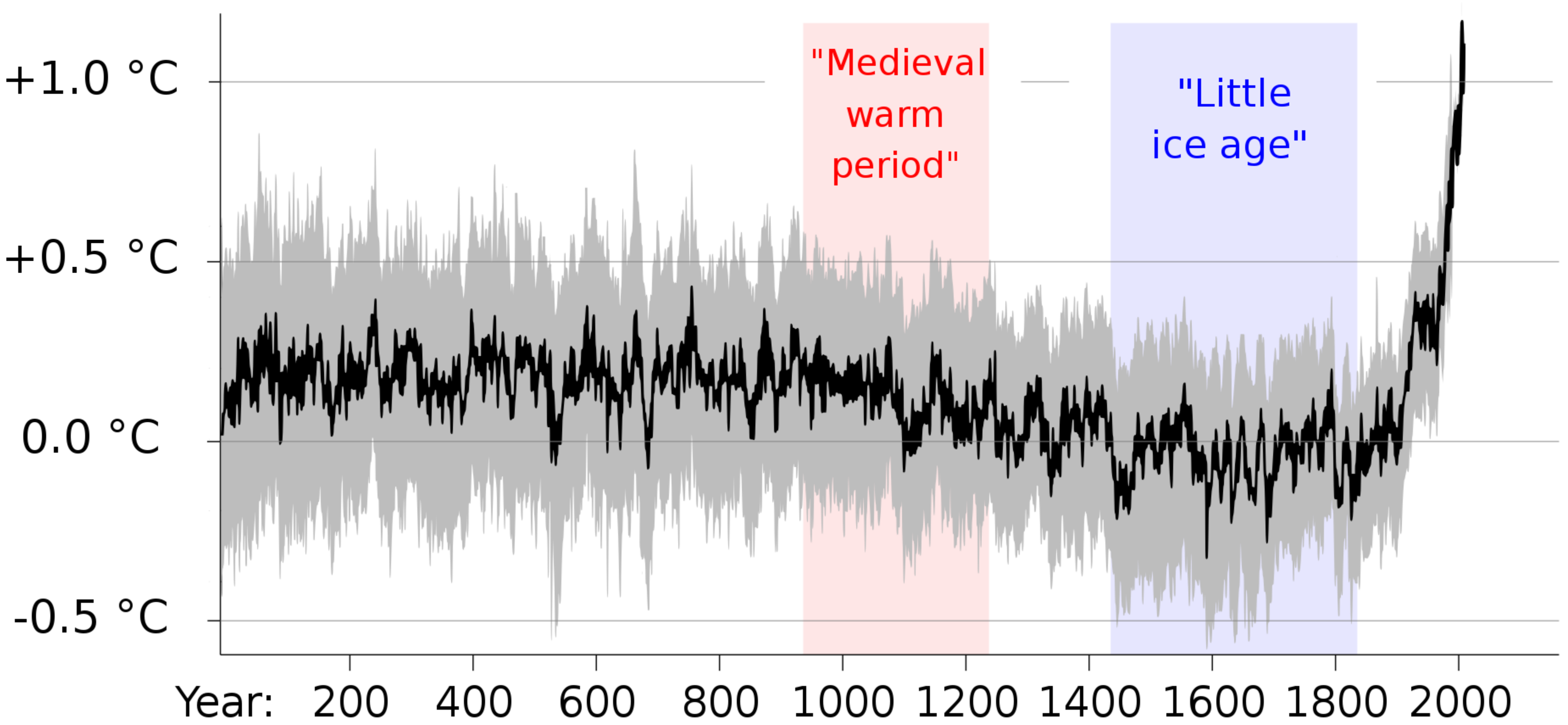


The exact physiological mechanism behind coral bleaching is under debate.
Several mechanisms were proposed: ROS, Apoptosis, membrane fluidity, microbial interactions and more..



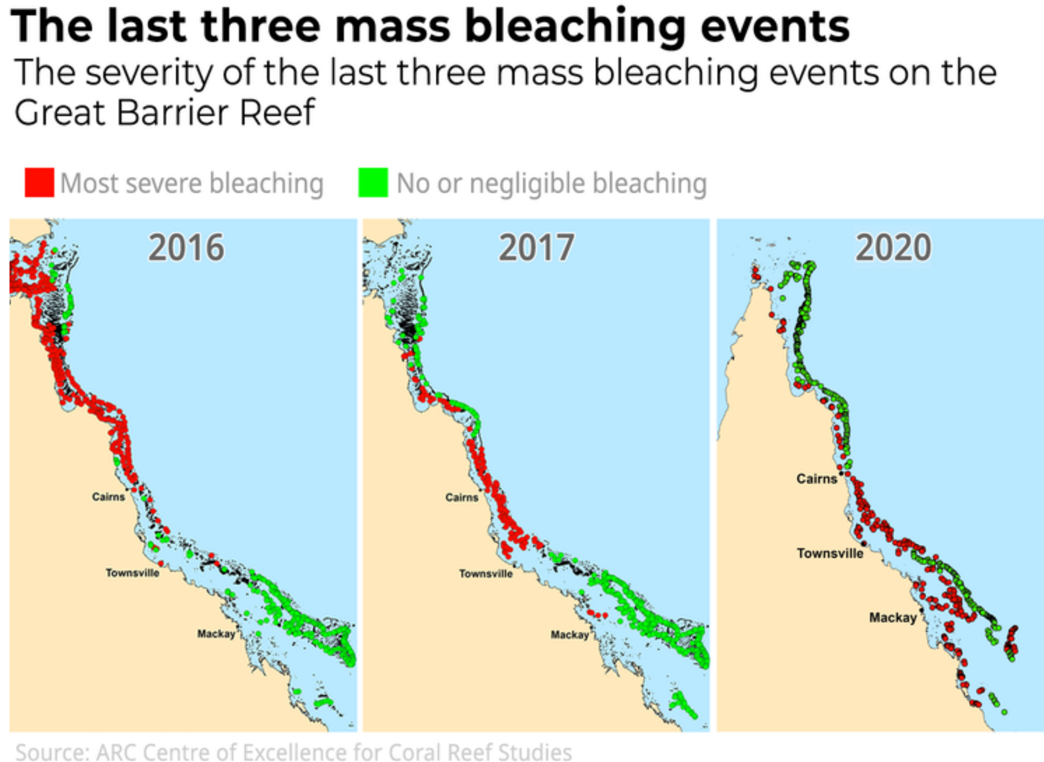
Annual Average
Ten-Year Moving Average
Continuation of Trend Since 1980
~2.0 °C by 2063
~1.5 °C by 2036
Data from Berkeley Earth (www.BerkeleyEarth.org)
Global temperature anomalies relative to 1850-1900 average
Global Temperature Anomaly (° C)
2
1.5
1
0.5
0
-0.5
1850
1900
1950
2000
2050

Global Average Temperature Change

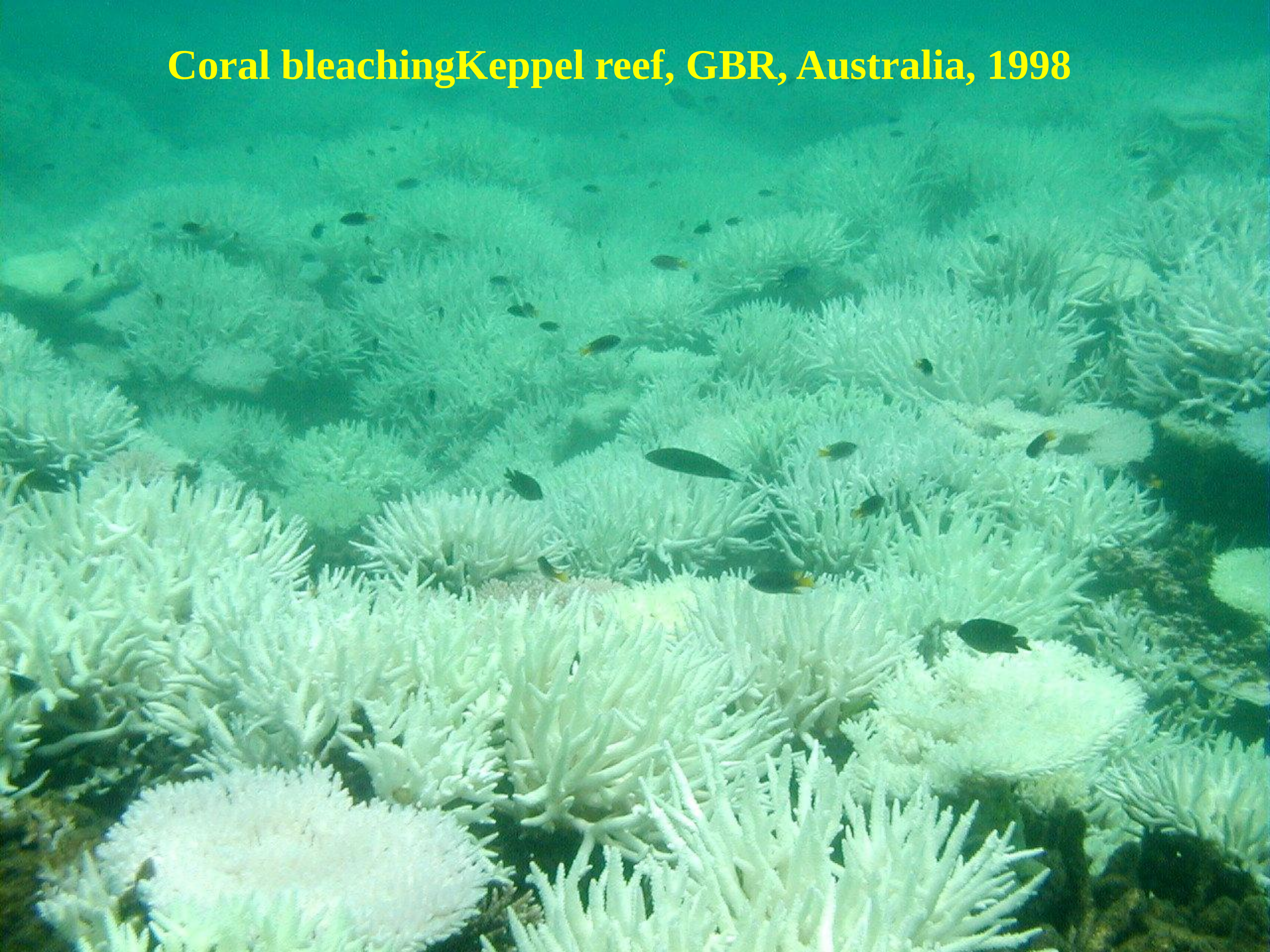


From graphic by Ed Hawkins. Data: from PAGES2k (and HadCRUT 4.6 for 2001-). Reference period: 1850-1900.

XL Catlan Seaview Survey



Coral bleachingKeppel reef, GBR, Australia, 1998



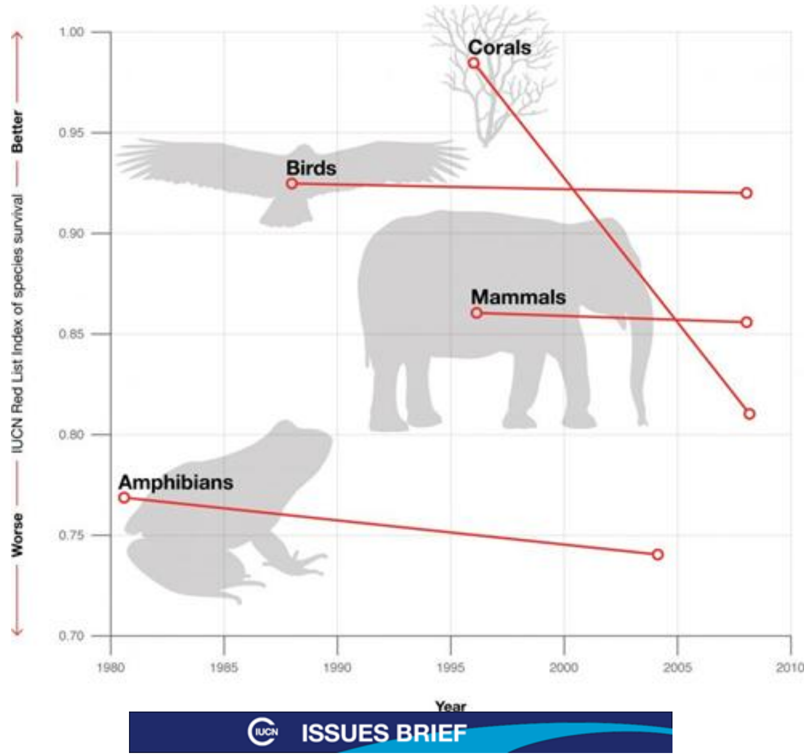
Lizard Island soon after bleaching

Lizard Island 3 years after bleacing




Summary

- Coral reefs are the most beautiful, diverse and productive ecosystem in the ocean
- Highly productive reefs thrive in the oligotrophic open ocean by extracting plankton as a source of nutrients
- Global changes: eutrophication, ocean acidification and global warming destroy these ecosystems
- More than 50% of the corals in the world have bleached and the rate of bleaching is increasing in time and space
- Coral reefs are perhaps the first marine ecosystems that will disappear due to global change




One Tree Island GBR

One Tree Island, GBR 2009

Lizard Island Expeditions: Sep.-Oct, 2008; Oct.-Nov., 2009

The End