The coral reefs of Micronesia and their future

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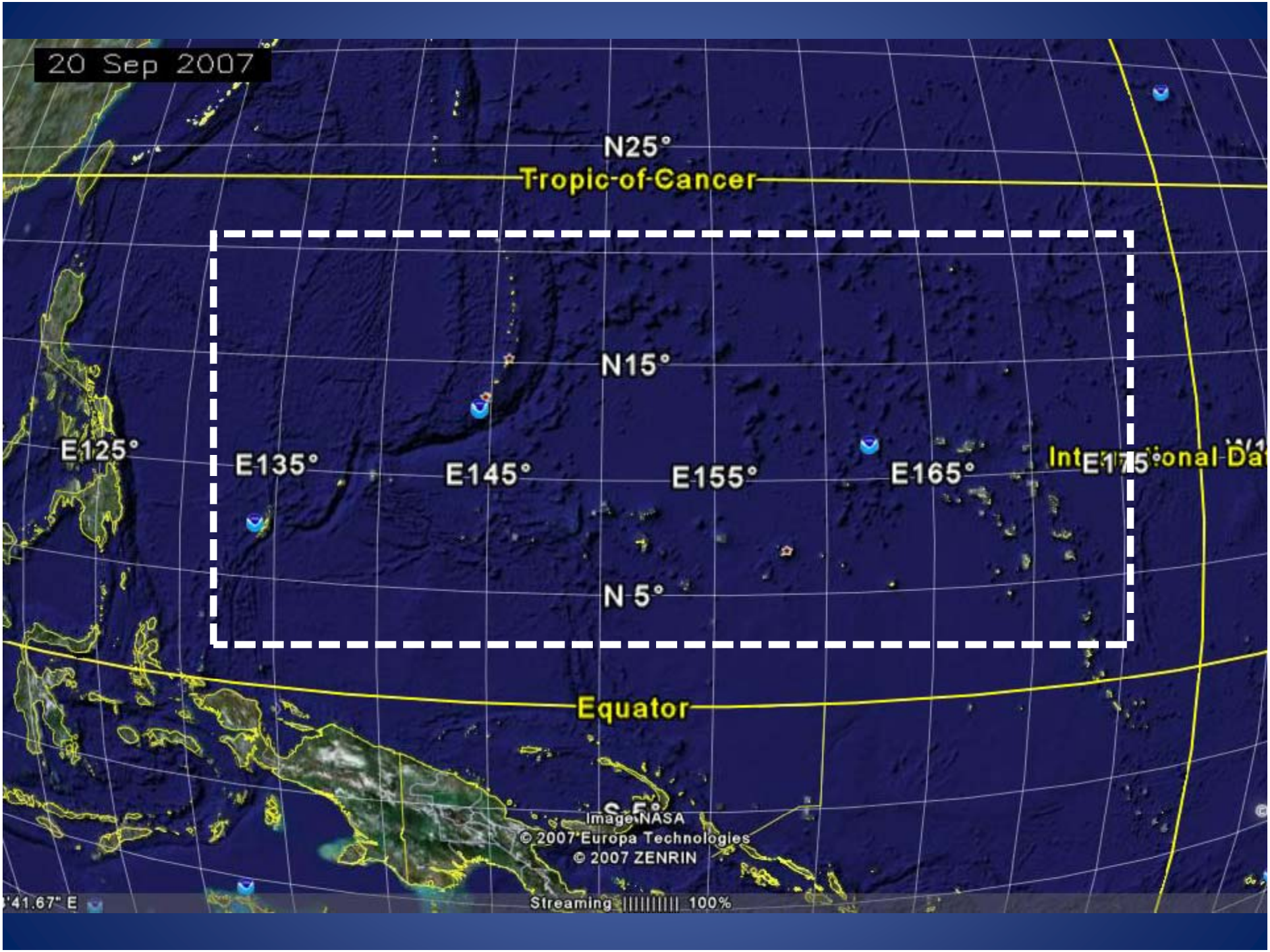
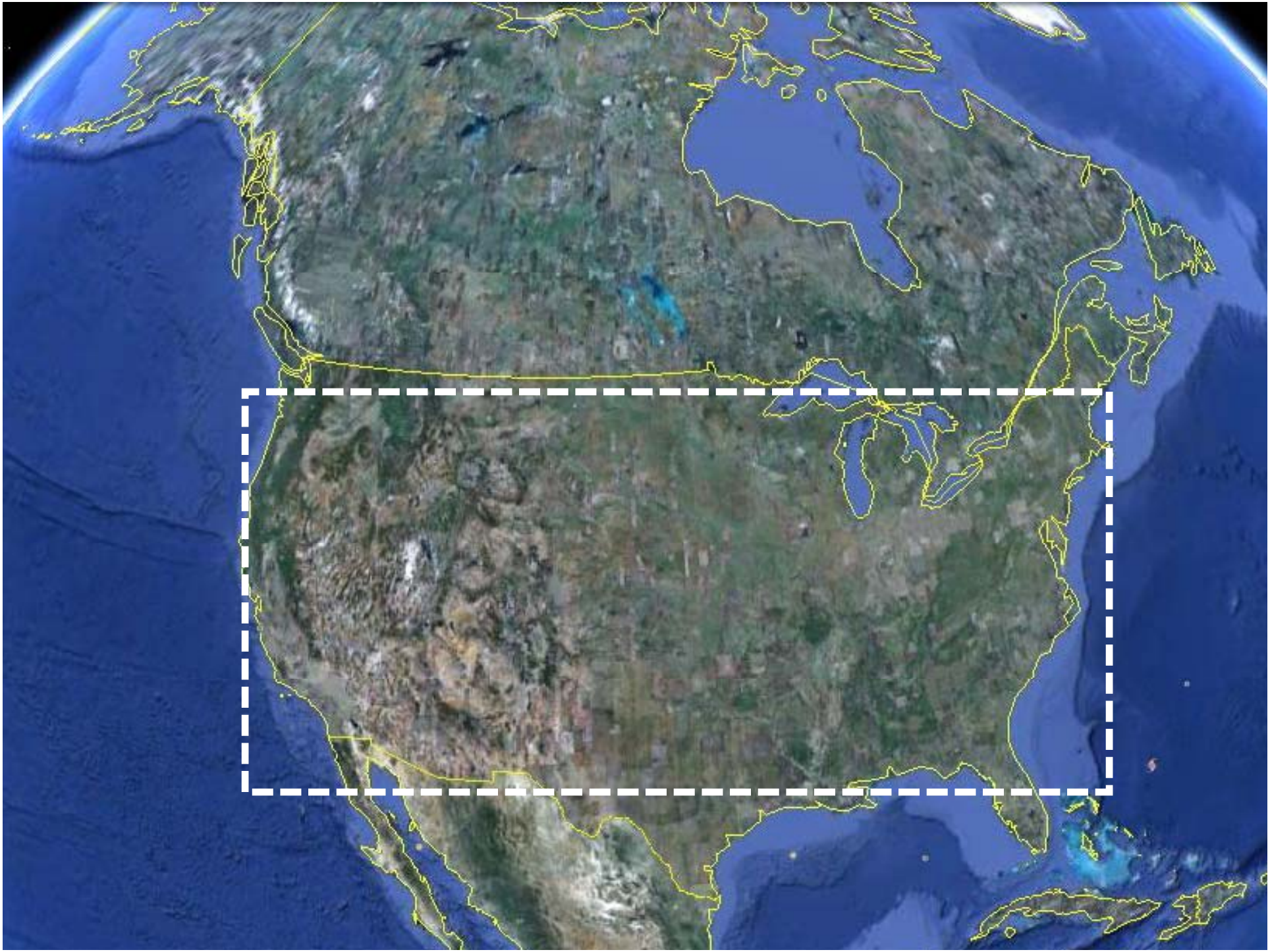
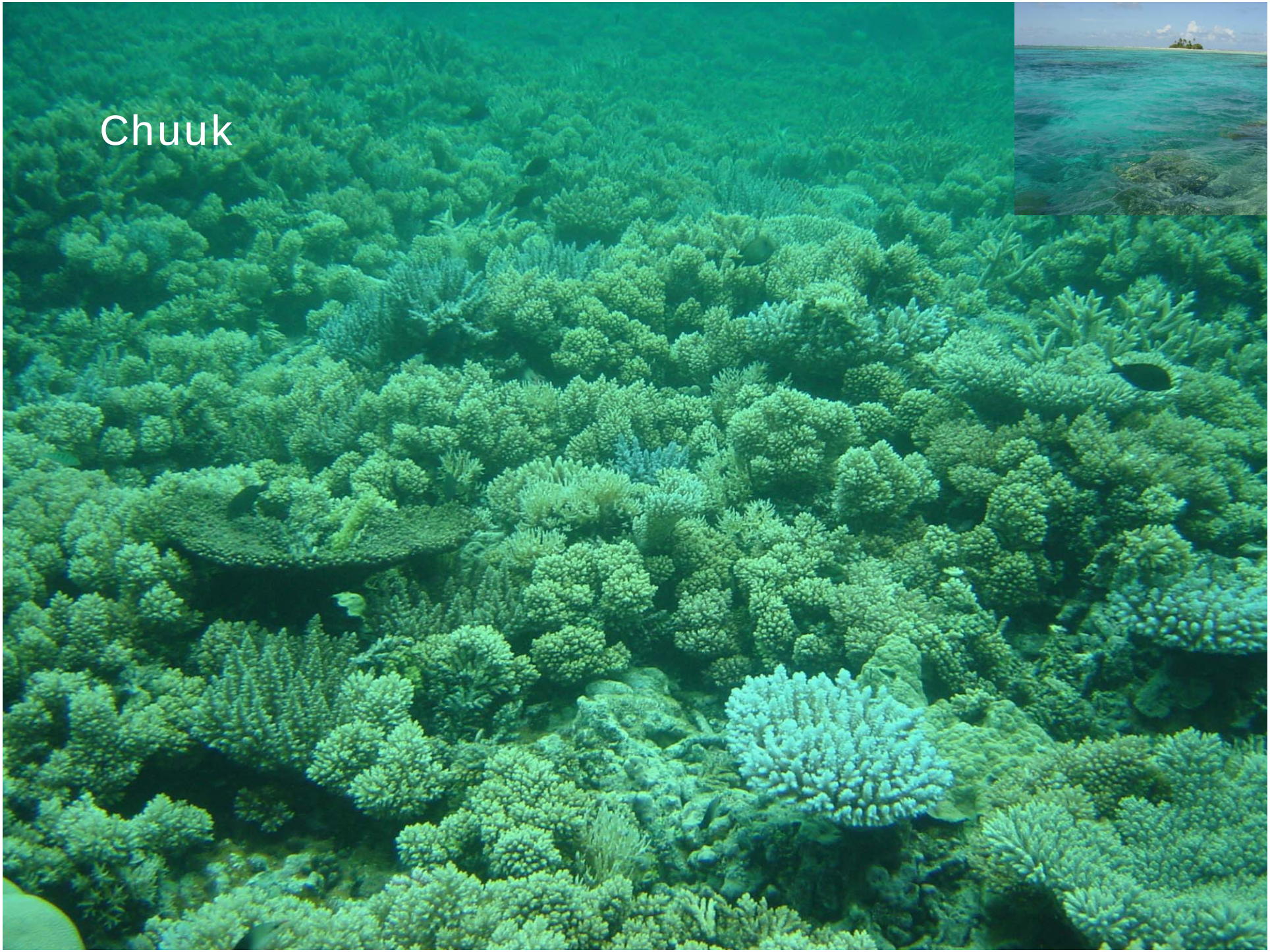
Florida Institute of Technology


20 Sep 2007
N25°
Tropic-of-Cancer
N15°
E125°
E135°
E145°
E155°
E165°
N 5°
Equator
Image NASA
© 2007 Europa Technologies
© 2007 ZENRIN
Streaming 100%



Palau

Gachung, Yap


Chuuk

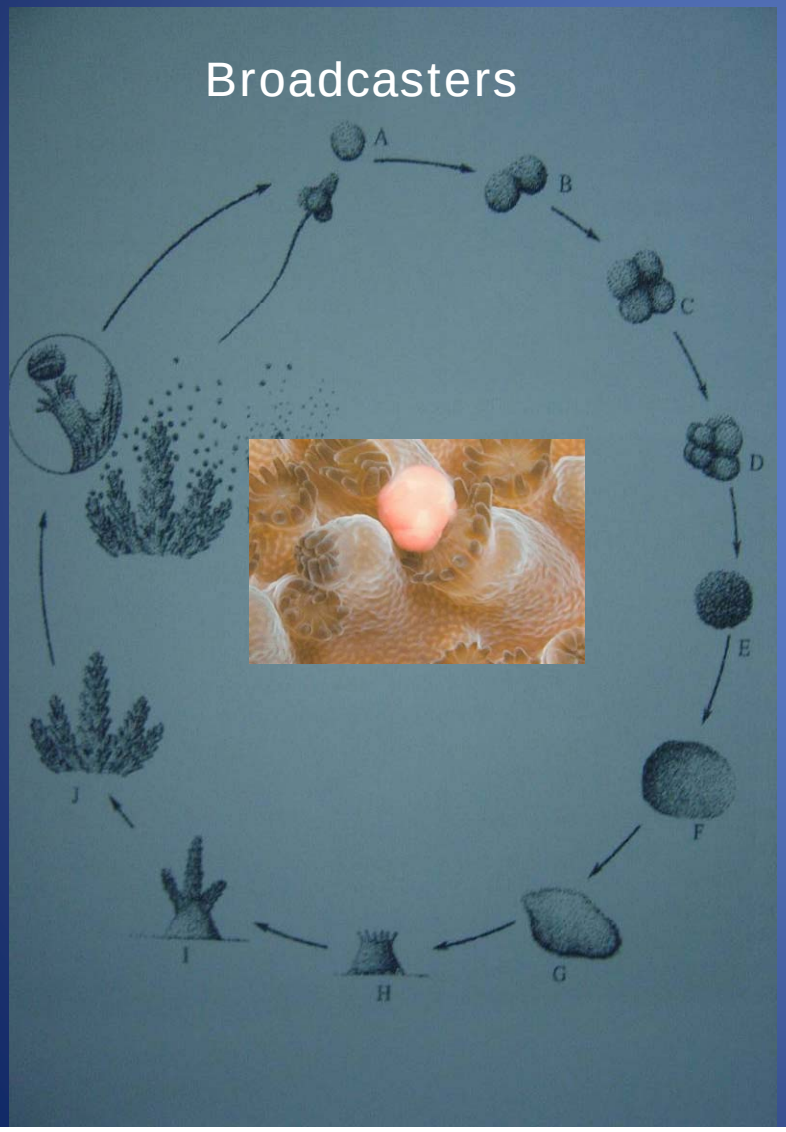
Pohnpei

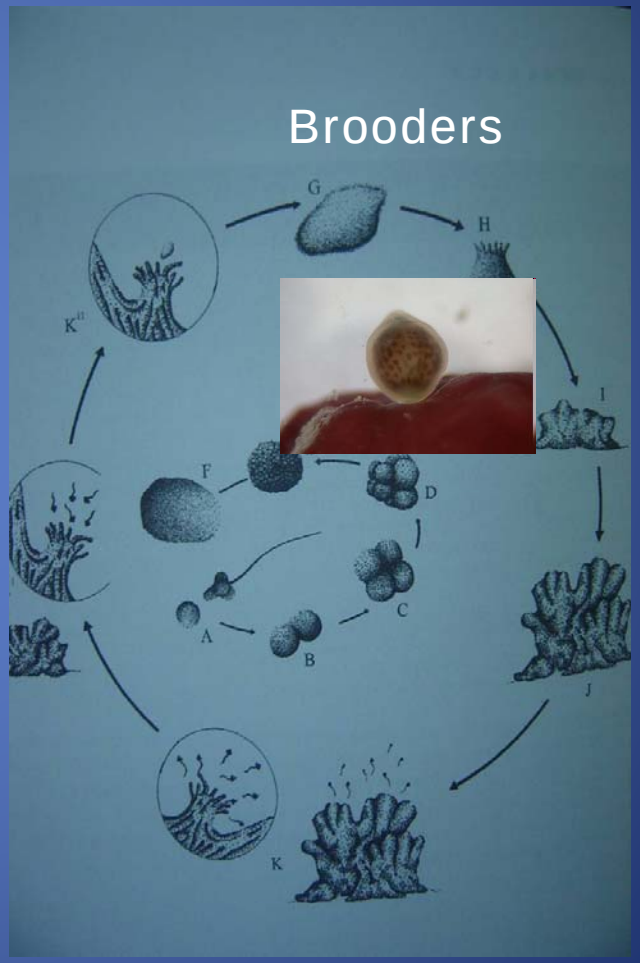
Kosrae

Majuro, RMI

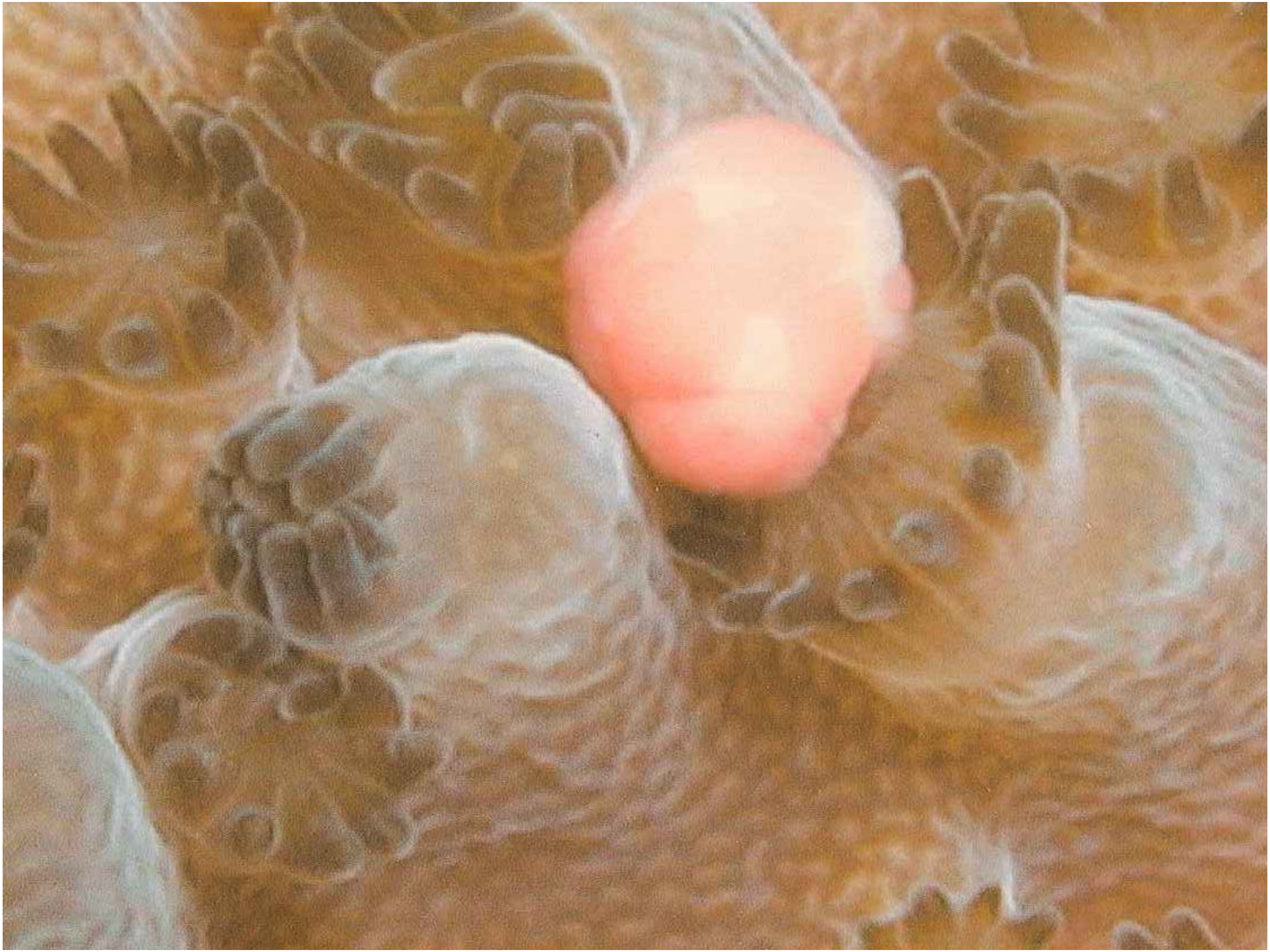
Saipan, CNMI

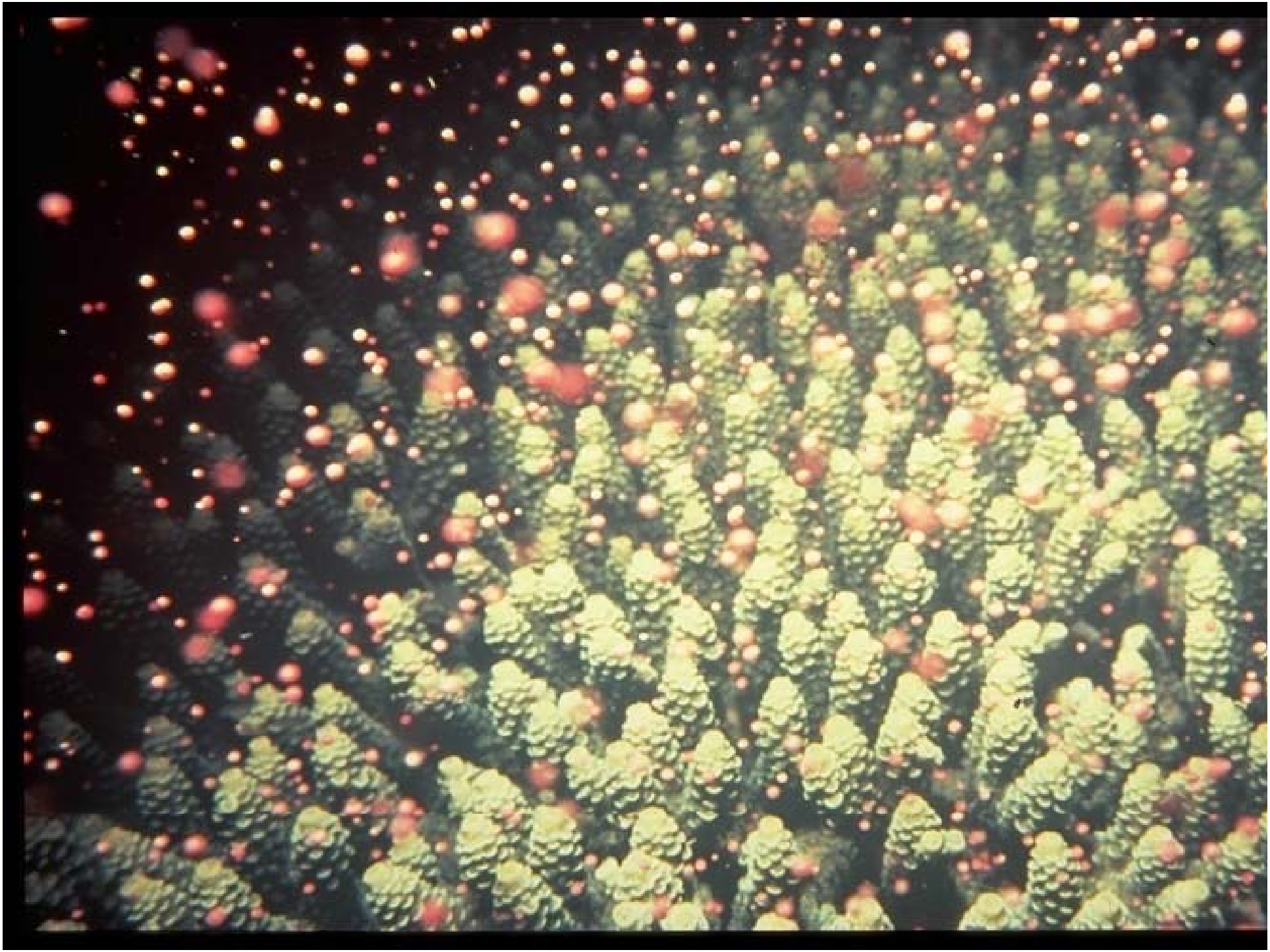
Reproduction

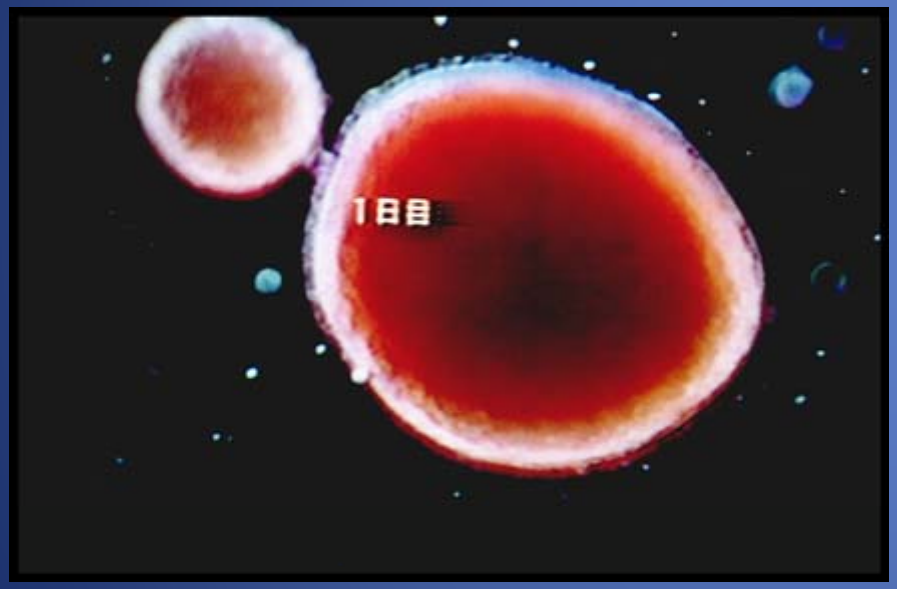




Wallace (1999) Staghorn corals of the world



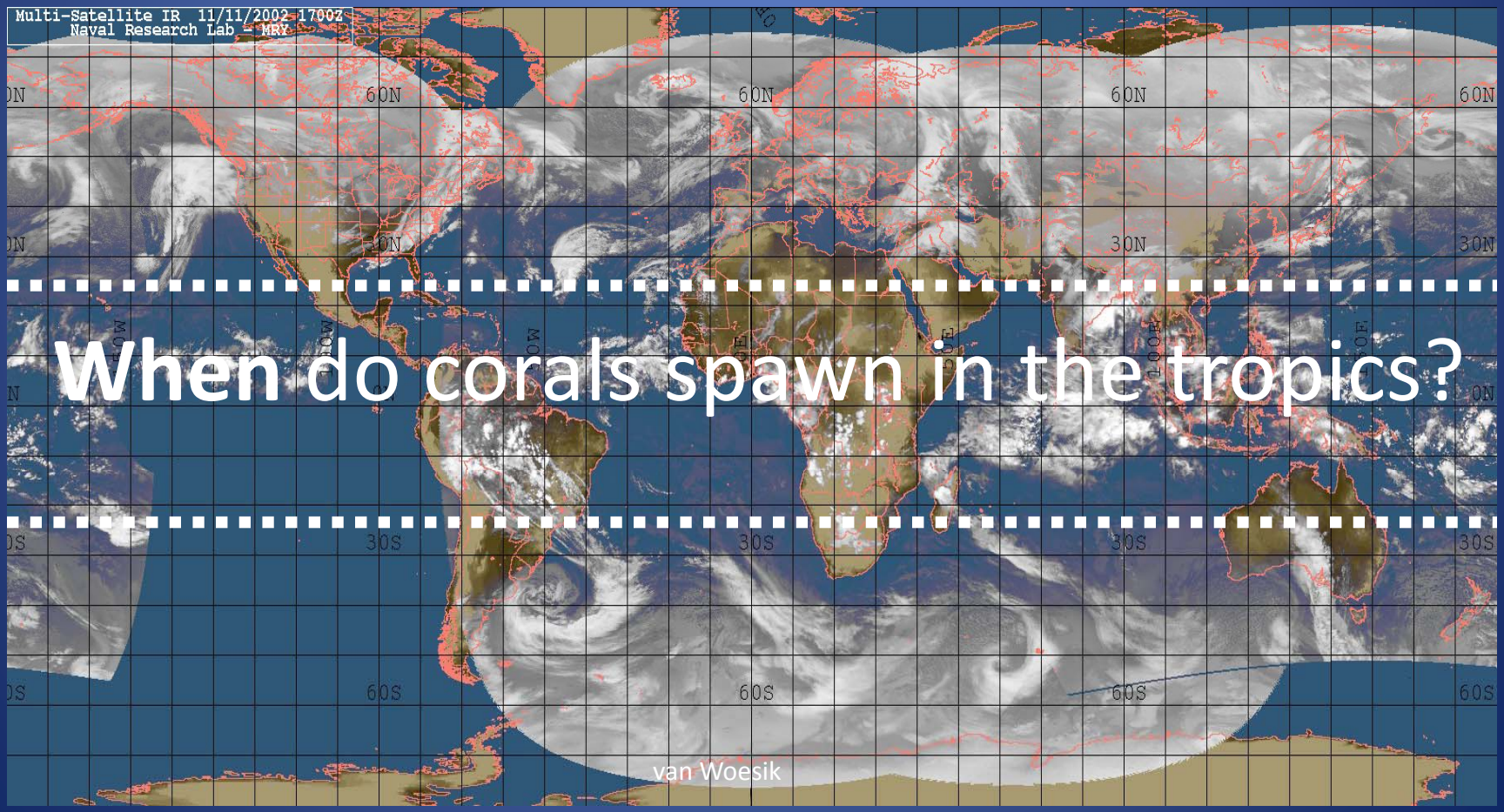




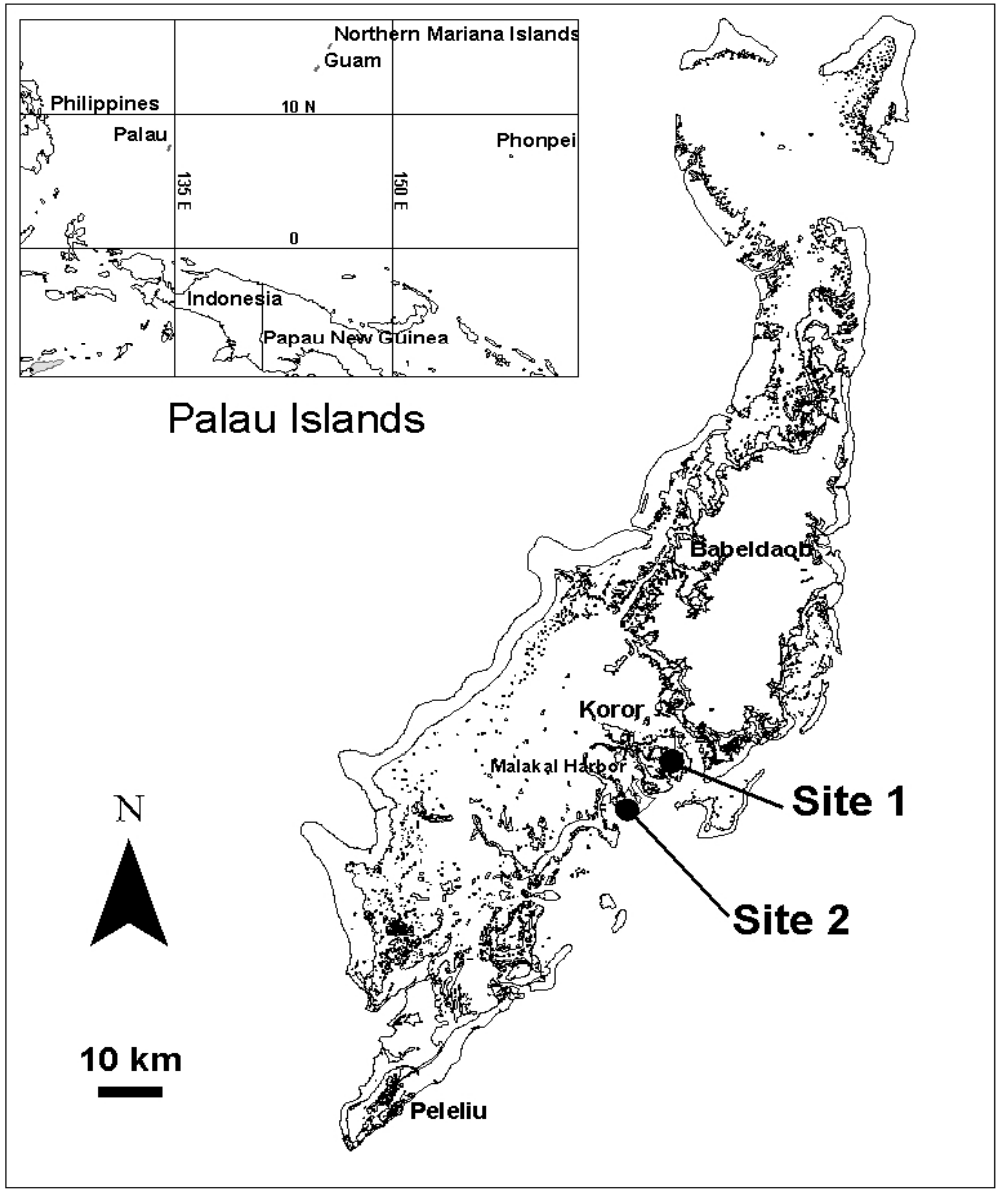
Day 1

Day 3-4

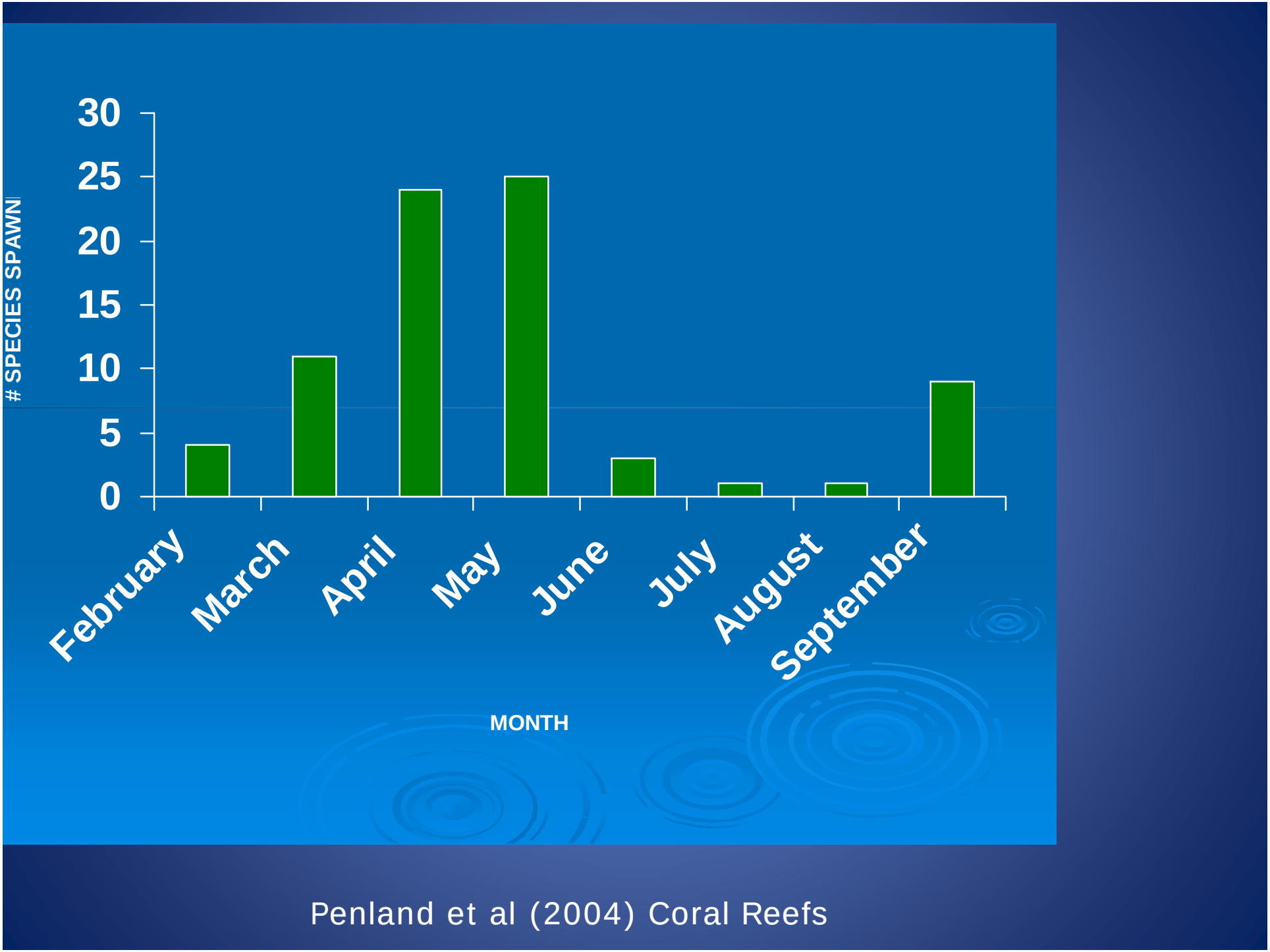
Previously coral spawning synchronicity was considered *unlikely in the tropics*



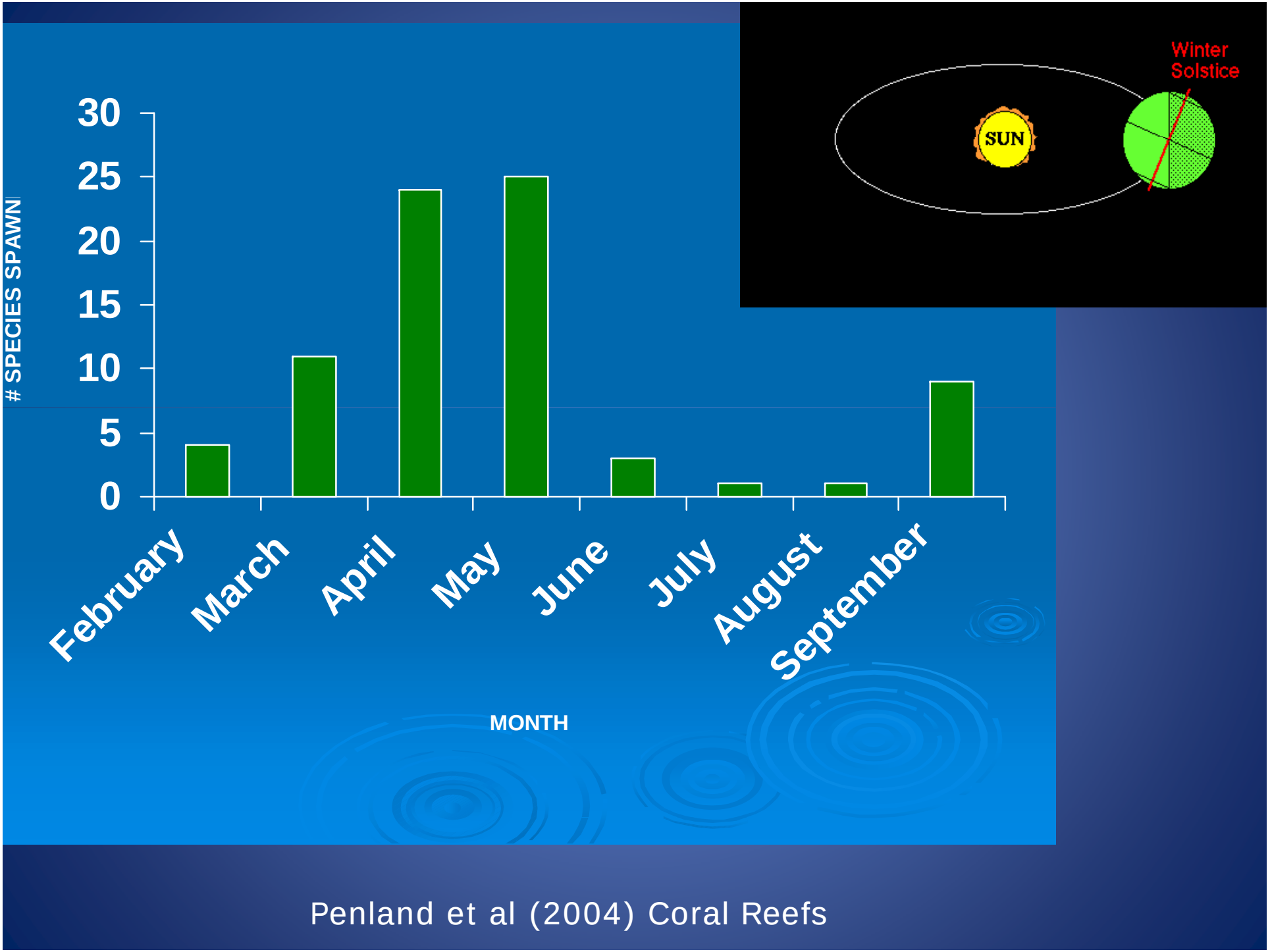
Palau



Penland, Kloulechad, Idip, and Van Woesik (2004) *Coral Reefs 23: 133-140*

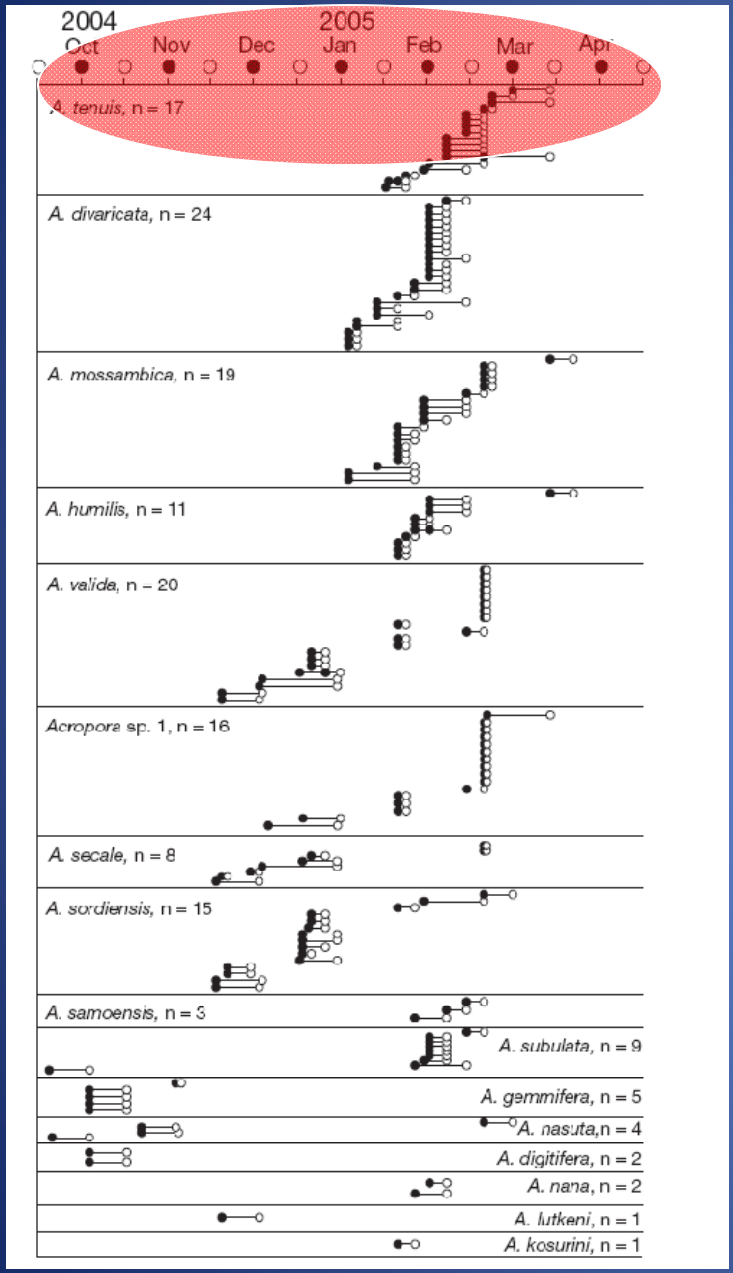


Penland et al (2004) Coral Reefs



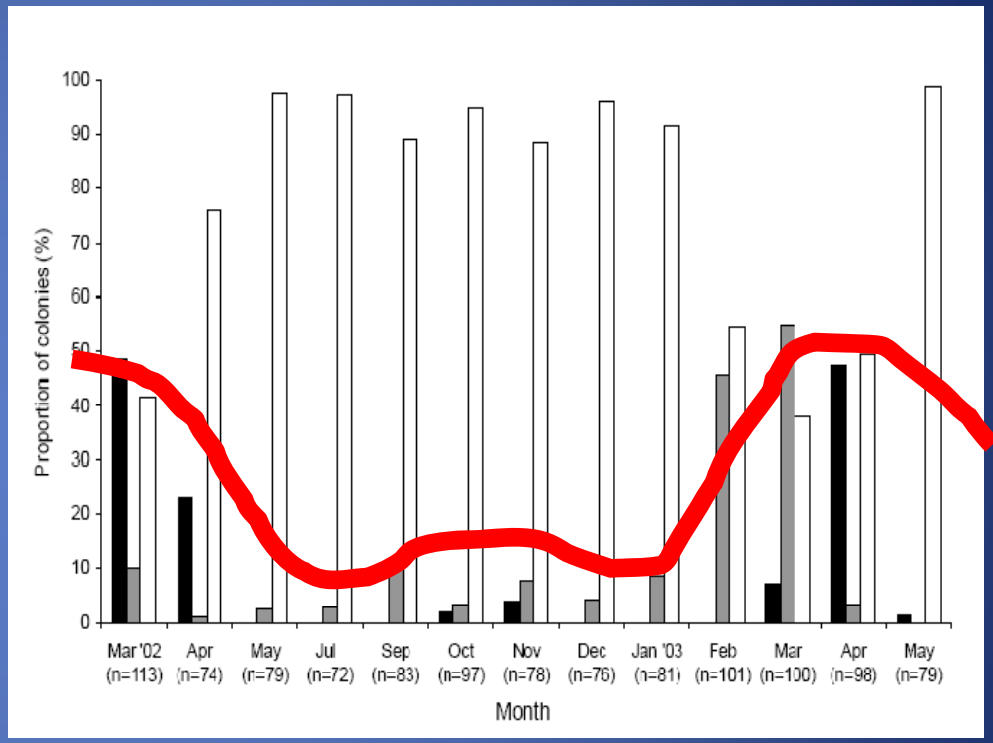
Penland et al (2004) Coral Reefs

Kenya



Mangubhai & Harrison 2008. MEPS 360: 85-96

Singapore



Guest et al 2005. Coral reefs 24: 112-

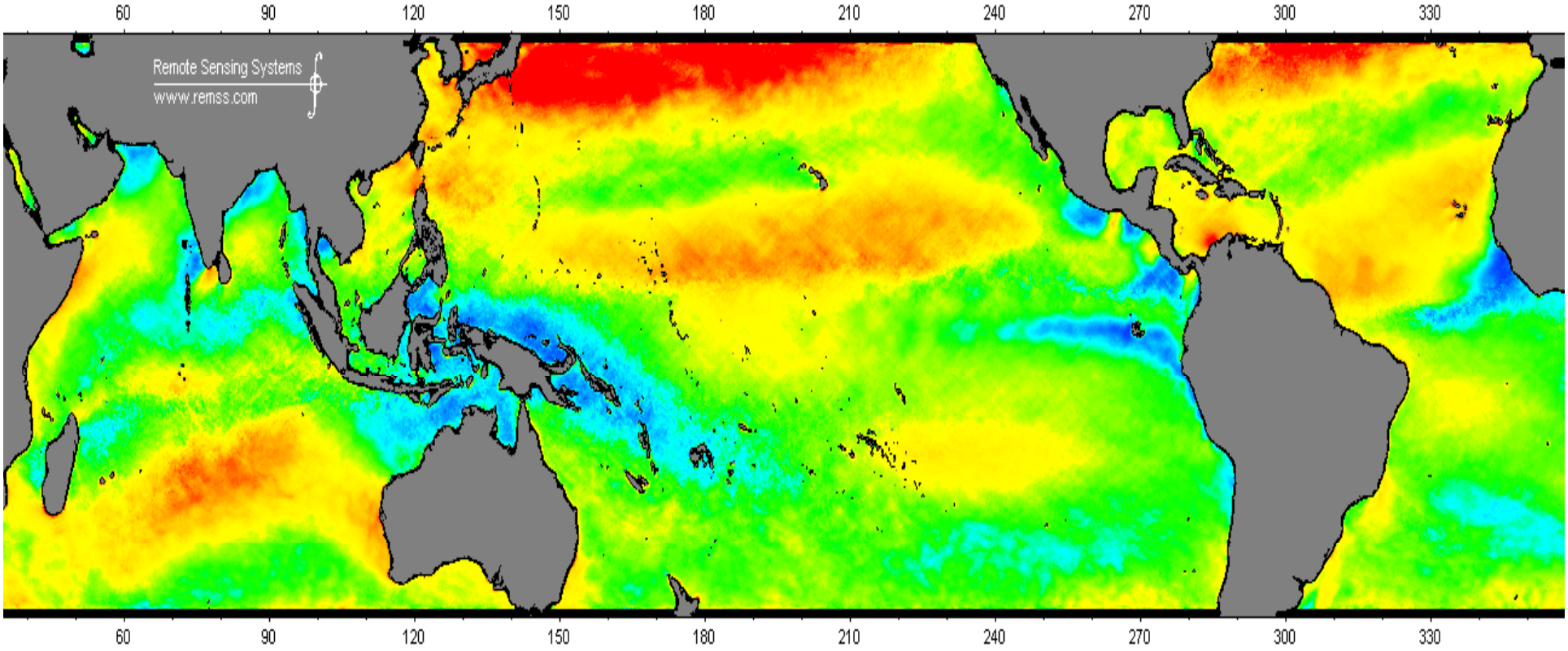
Questions

- Why does the coral spawning season vary regionally?
- Is the duration of the spawning season driven by an environmental factor?
- Is an extended spawning season the default system, suggesting that gamete release is subjected to strong selective pressures?

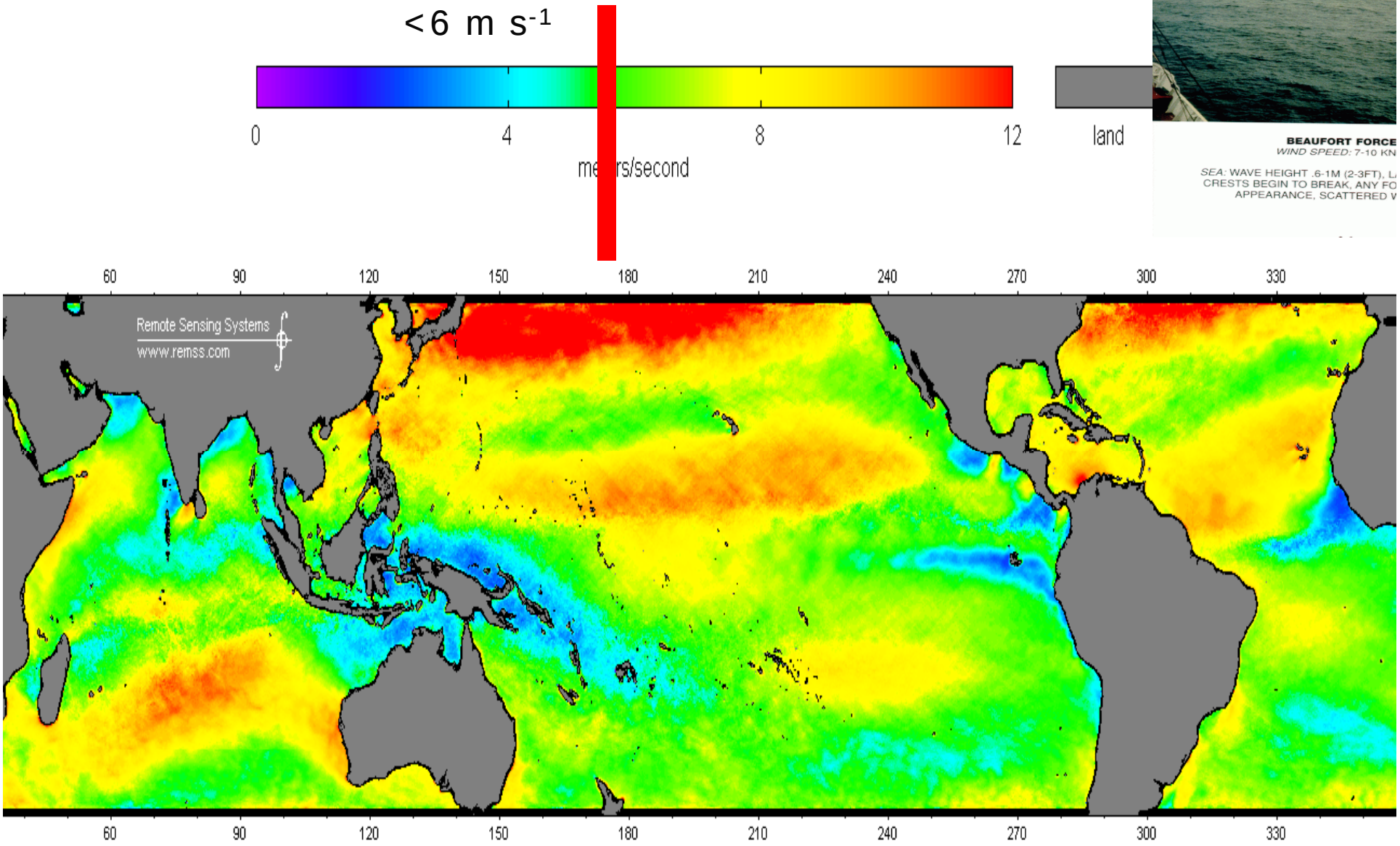
Ultimate cues – Why?

- What is the long-term advantage (adaptive significance) of mass spawning?

Hypothesis: windy seasons are strong filters – strong selection against spawning outside calm periods (i.e., gametes lost from reef during windy conditions)



TMI Monthly Averaged Wind Speed (Using 11 GHz Channel):

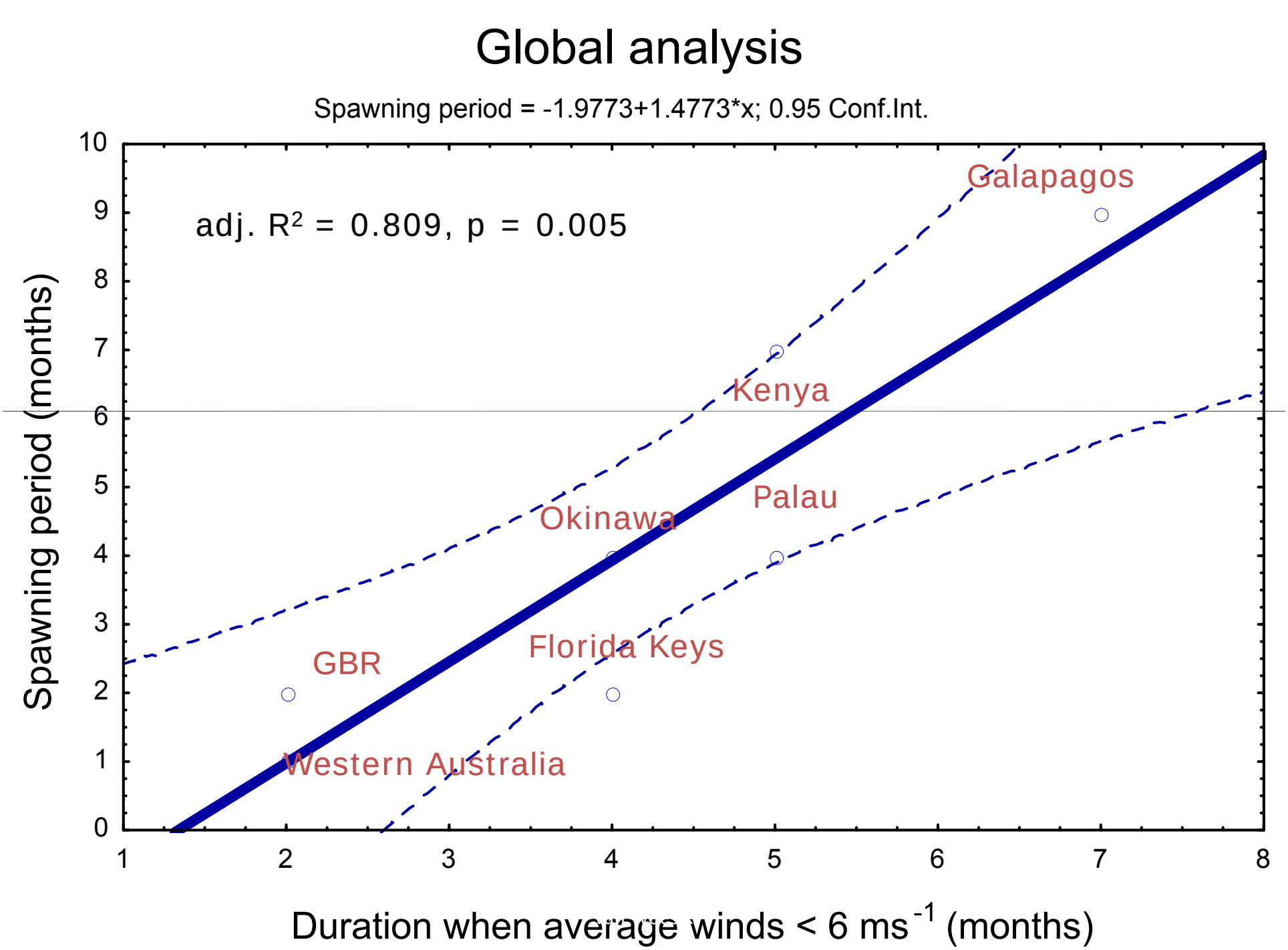


BEAUFORT FORCE
WIND SPEED: 7-10 KN

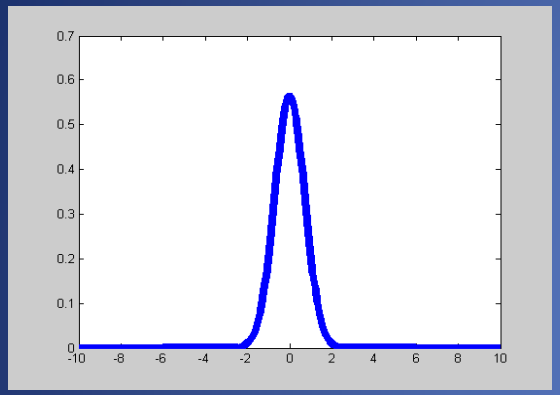
SEA: WAVE HEIGHT .6-1M (2-3FT), L
CRESTS BEGIN TO BREAK, ANY FO
APPEARANCE, SCATTERED

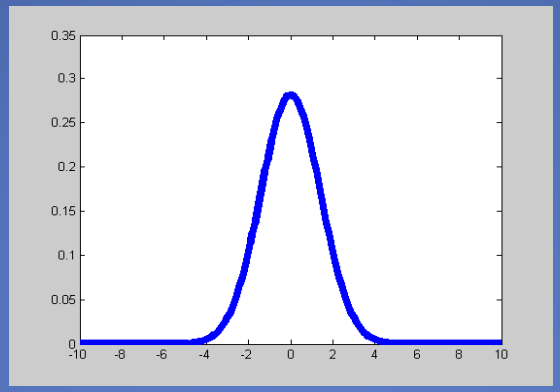
Global analysis – Tropical Microwave Imager (TMI) data, randomly selected pixel in reef vicinity, for each month (from 1999 to 2007)

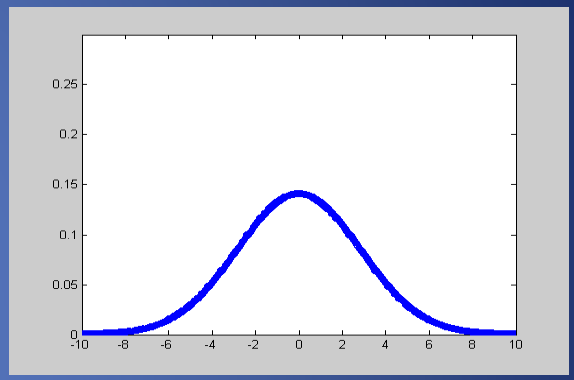
- **Great Barrier Reef (latitude 19°S)**
- **Okinawa (26°N)**
- **Palau (7°N)**
- **Kenya (3°S)**
- **Galápagos (0°)**
- **Ningaloo (21°S)**
- **Florida Keys (24°S)**


Global analysis
Spawning period = -1.9773+1.4773*x; 0.95 Conf.Int.
adj. R² = 0.809, p = 0.005
Galapagos
Kenya
Palau
Okinawa
Florida Keys
GBR
Western Australia
Spawning period (months)
Duration when average winds < 6 ms -1 (months)
0
1
2
3
4
5
6
7
8
9
10
1
2
3
4
5
6
7
8

Evolution of the system







Selective pressure

Evolve toward synchronization

Most derived

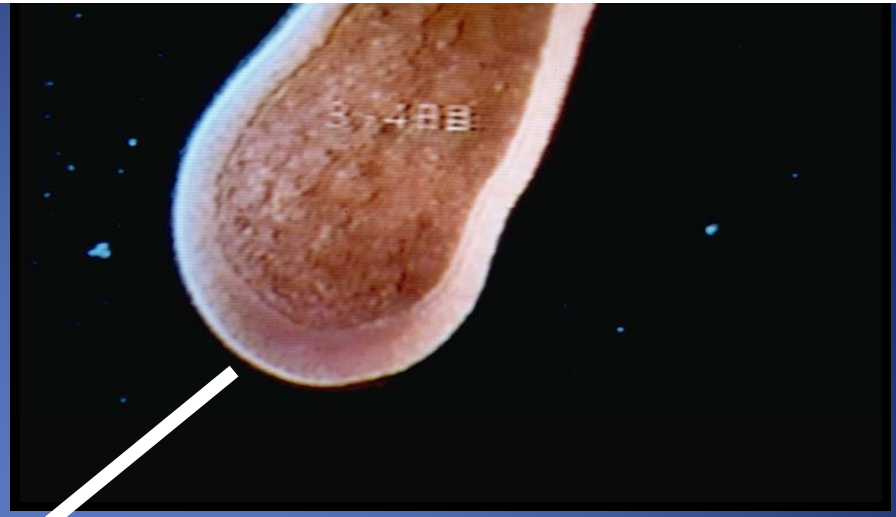
Ancient

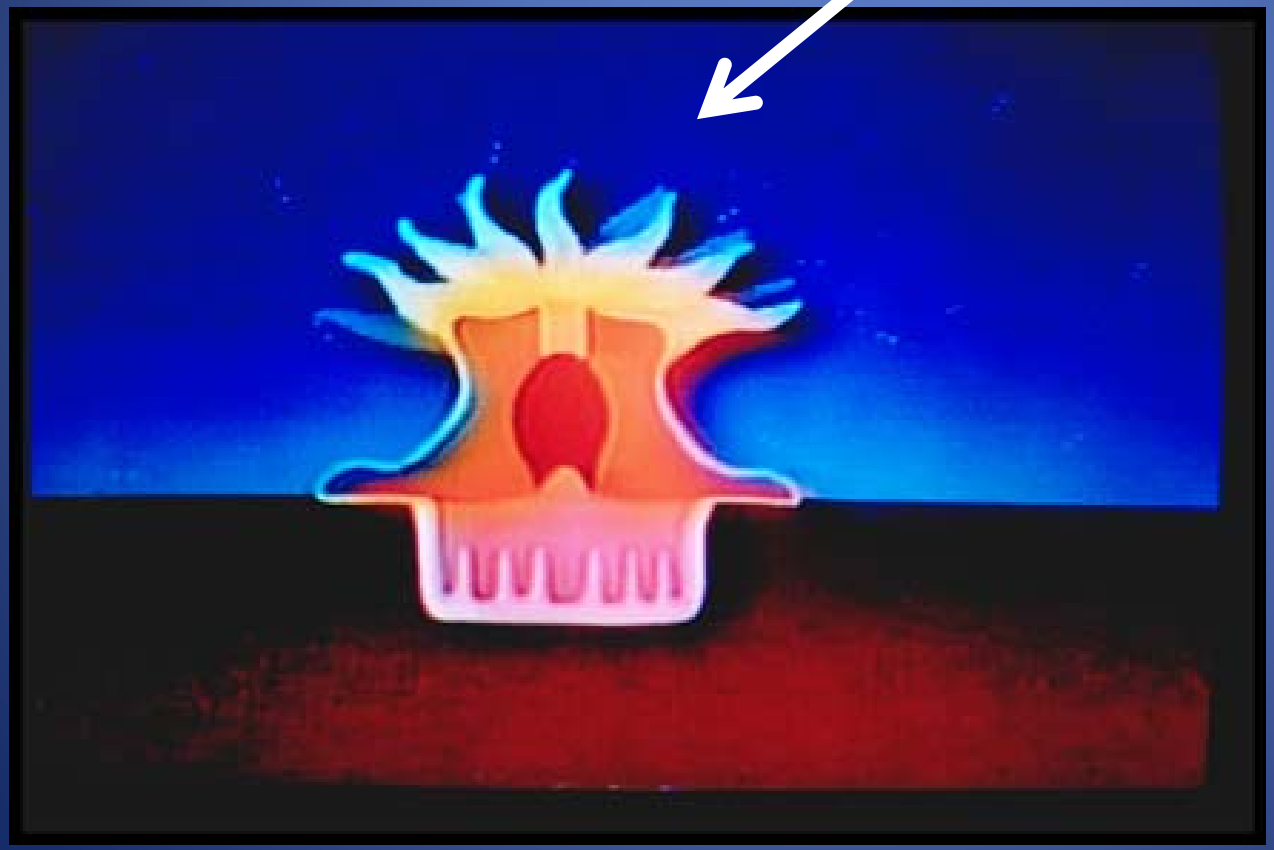
van Woesik (2010) Proc Royal Soc 277: 715-722

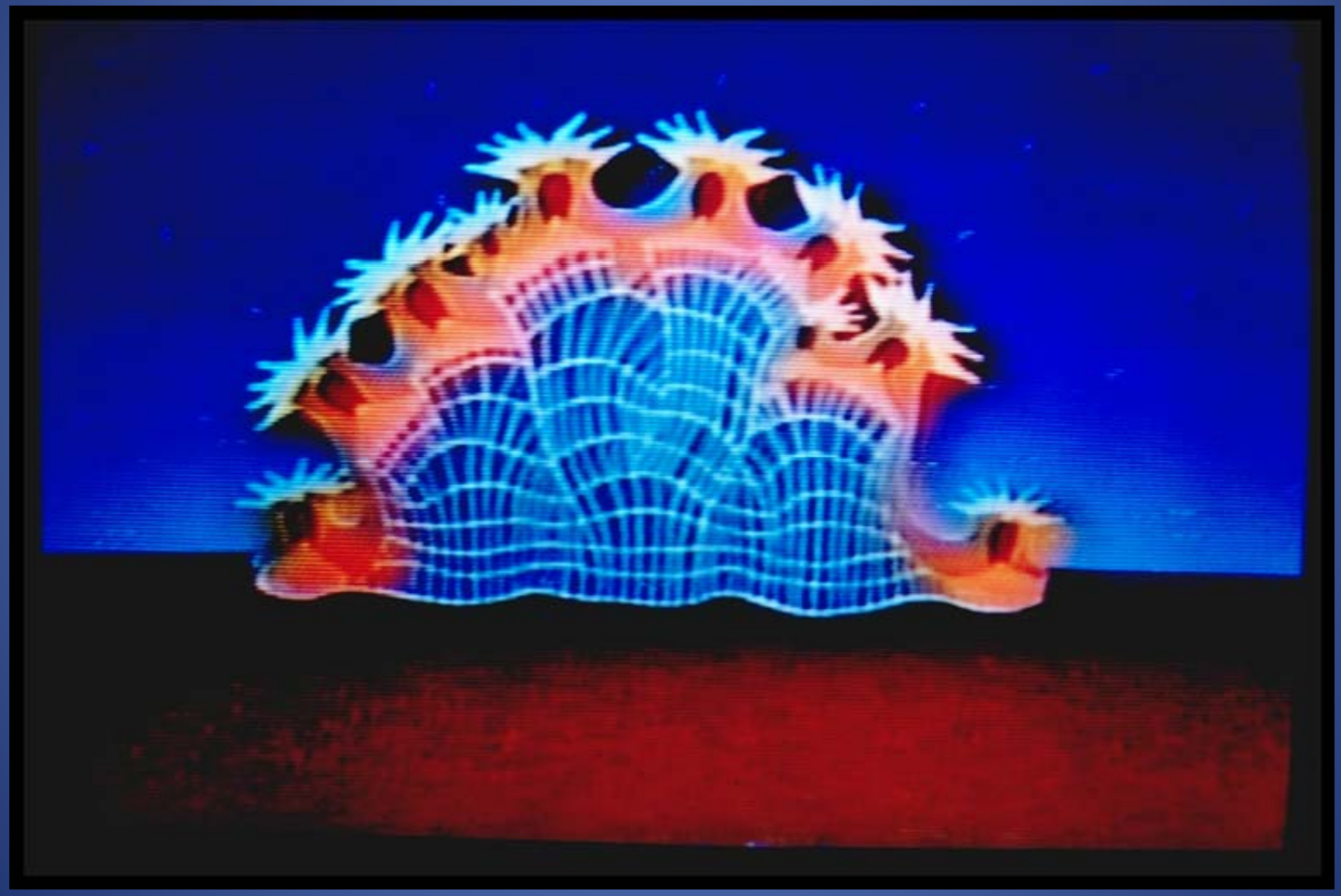
Infers high retention

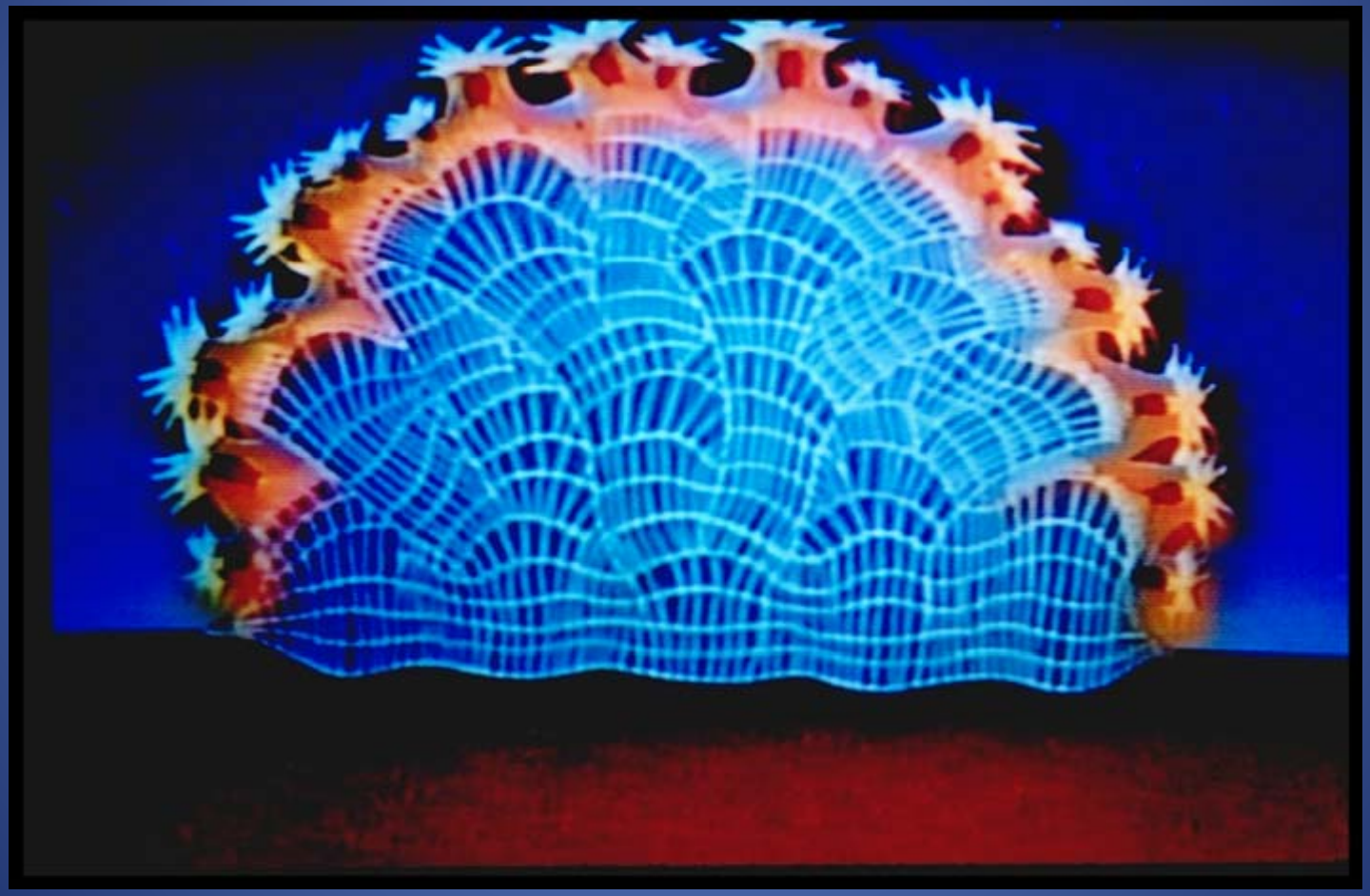
Synchronization of mass spawning during seasonally calm periods clearly agrees with recent genetic evidence of local dispersal (1-10 km) and high local retention

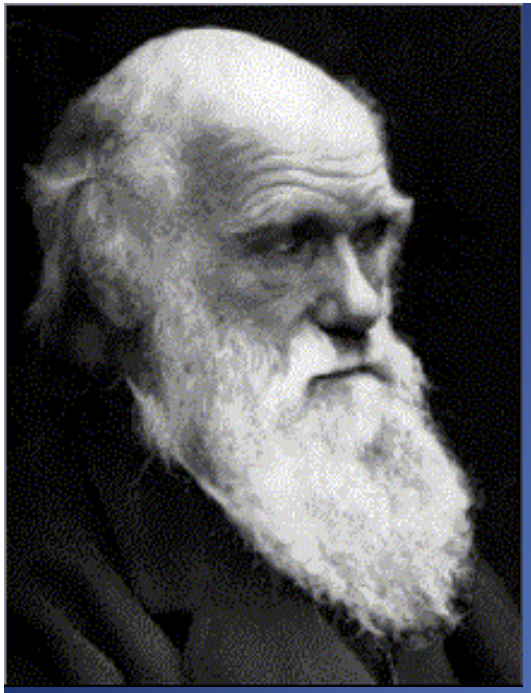
Ayre & Hughes (2000) Evolution 54(5): 1590-1605; Ayre & Hughes (2004) Ecology Letters 7: 273-278





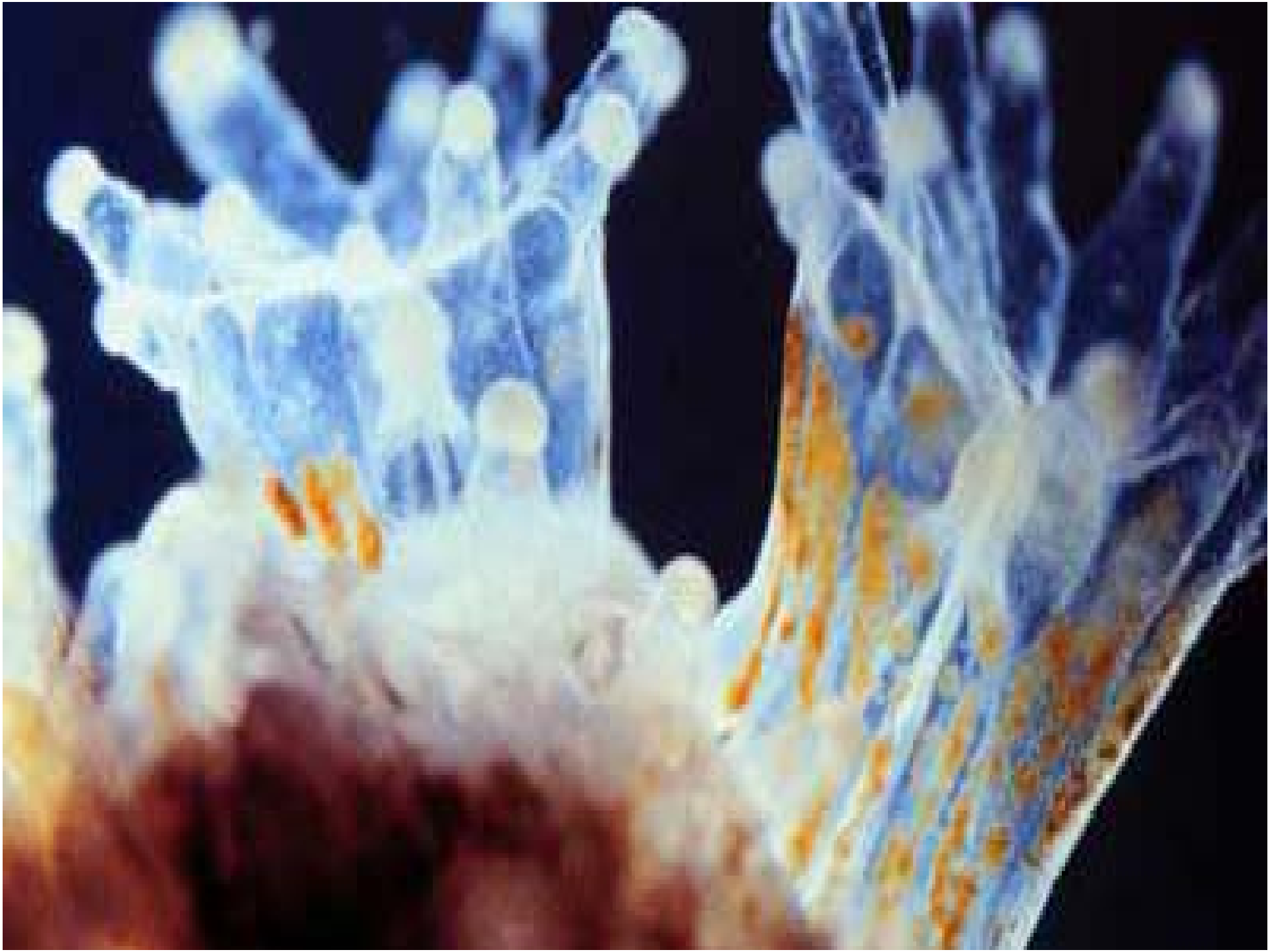






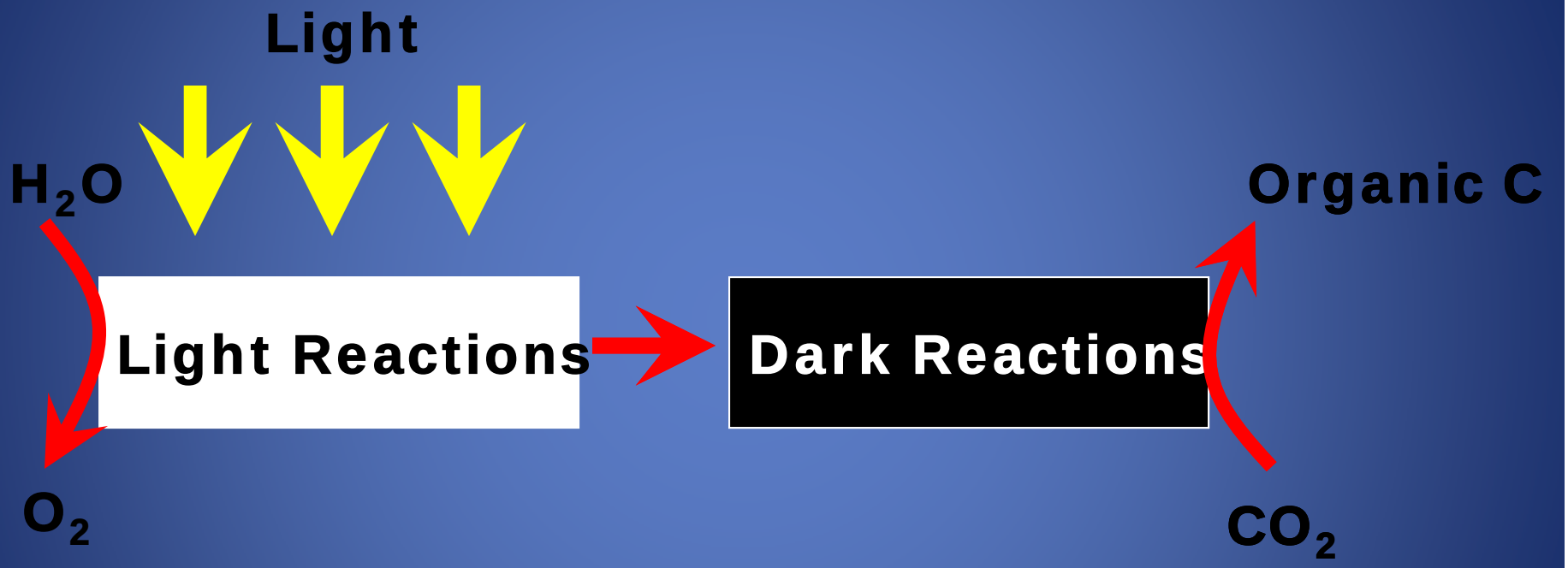
Darwin's dilemma

How do coral reefs thrive in low nutrient environments?

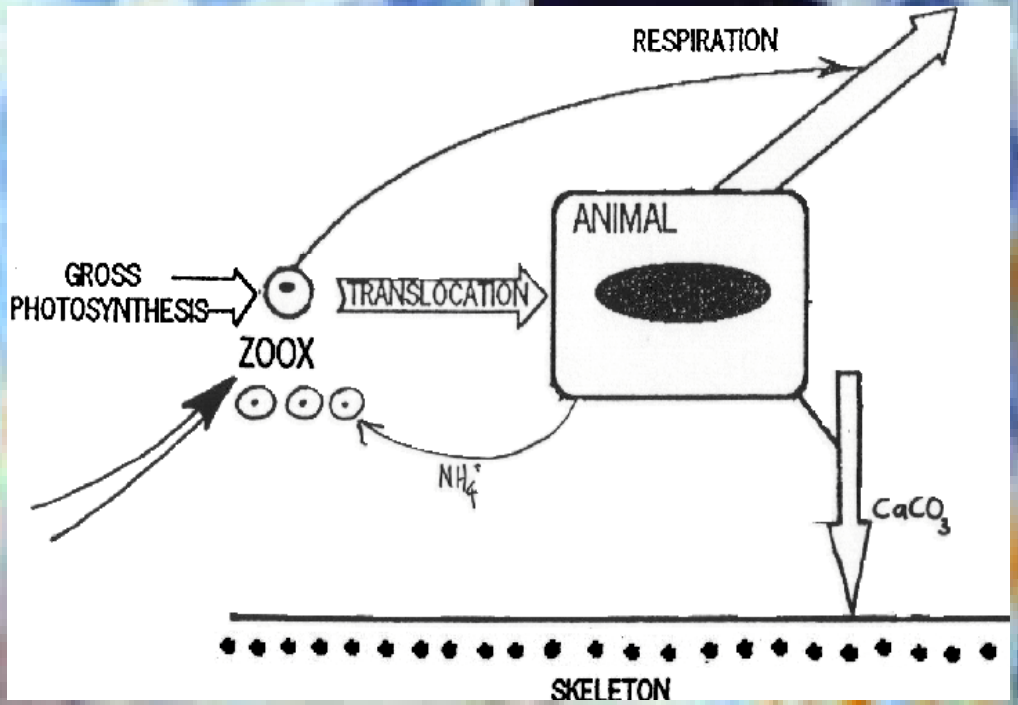


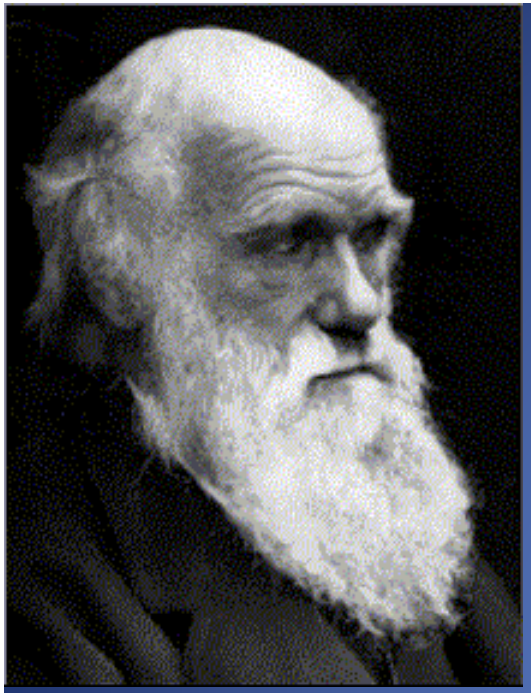
Photosynthesis

Normal temperatures



Symbiosis


RESPIRATION
ANIMAL
GROSS
PHOTOSYNTHESIS
TRANSLOCATION
ZOOX
NH_4^+
$CaCO_3$
SKELETON

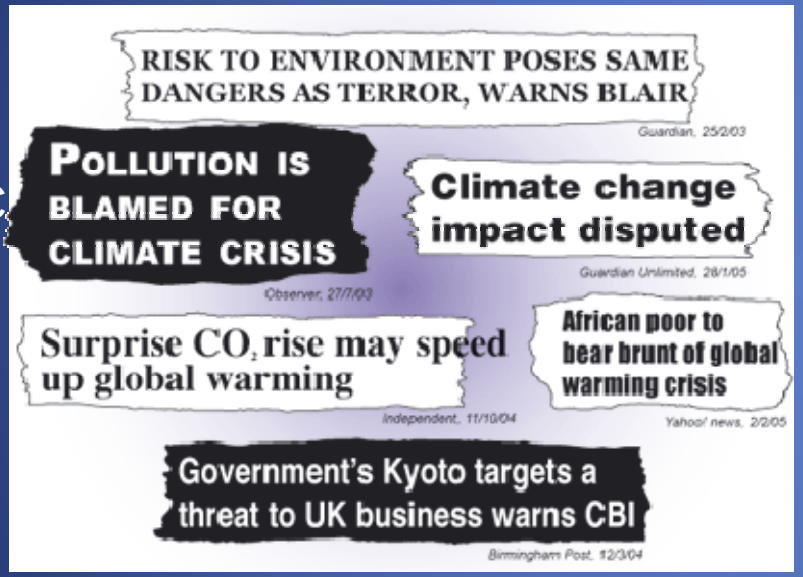


Darwin's dilemma: how do coral reefs thrive in low nutrient environments?

Symbiosis


Sustainability – a model system with over 245 million years of success
van Woesik

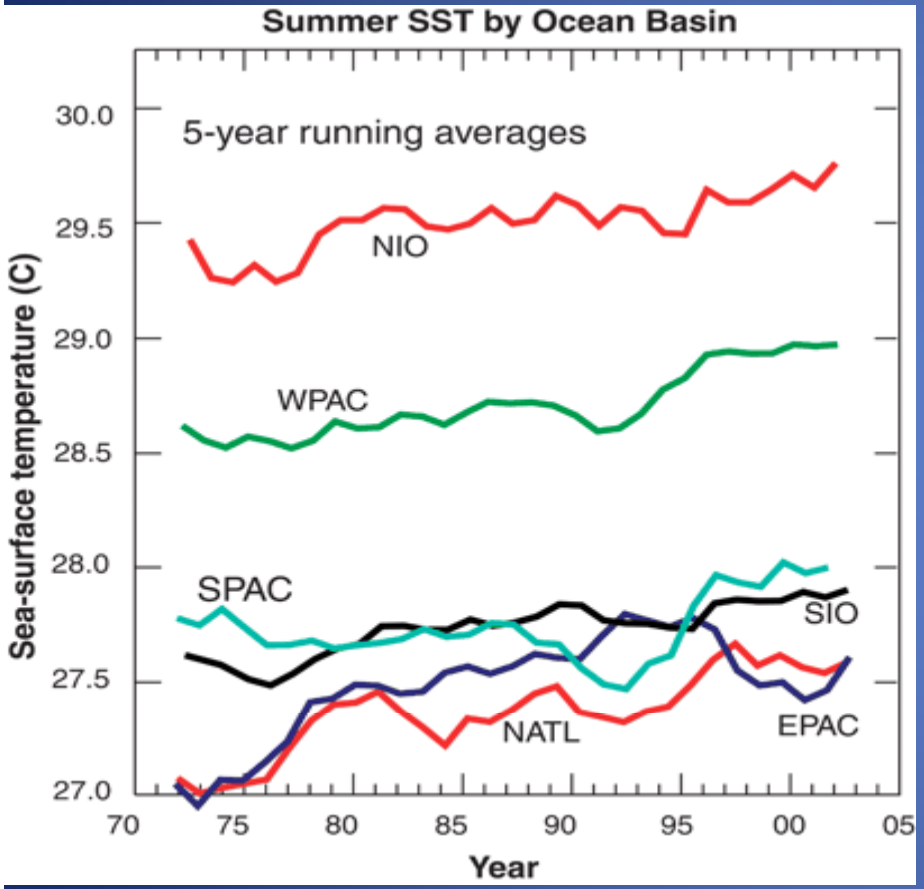
Global Climate Change

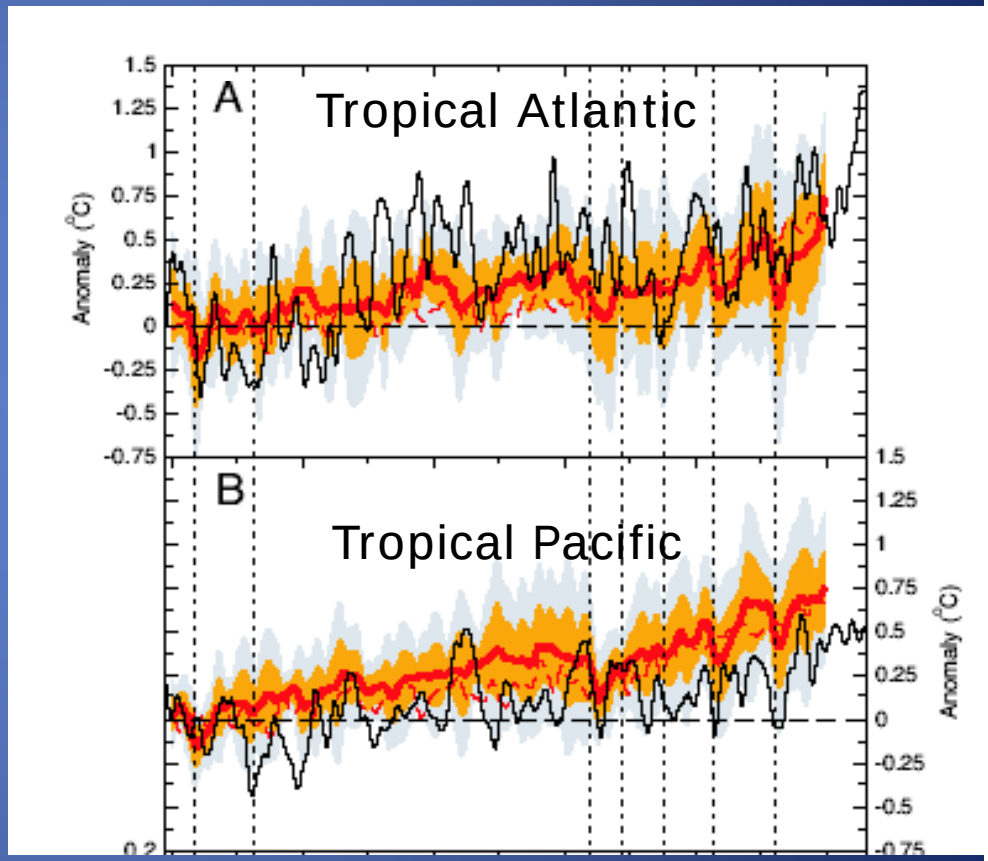


Global warming is:

… the unusually rapid increase in Earth's average surface temperature over the past century primarily because of the release of greenhouse gases by people that are burning fossil fuels.

Last 20 years – average increase of 0.5°C

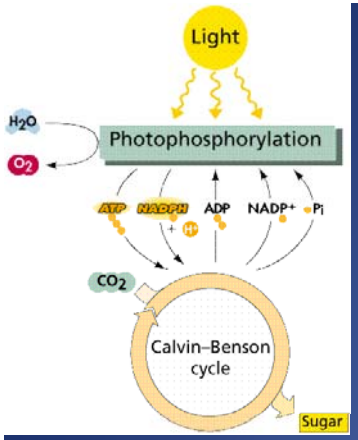




Webster et al 2005. Science

Santer et al 2006. PNAS 103: 13905-139

Symbiotic dysfunction



Photosynthesis

Normal temperatures

Light

H_2O

Organic C

Light Reactions

Dark Reactions

O_2

$^1O_2$

$^{**}O_2$

CO_2

Active Oxygen

BLEACHING

Oxidative DAMAGE

Capacity overwhelmed

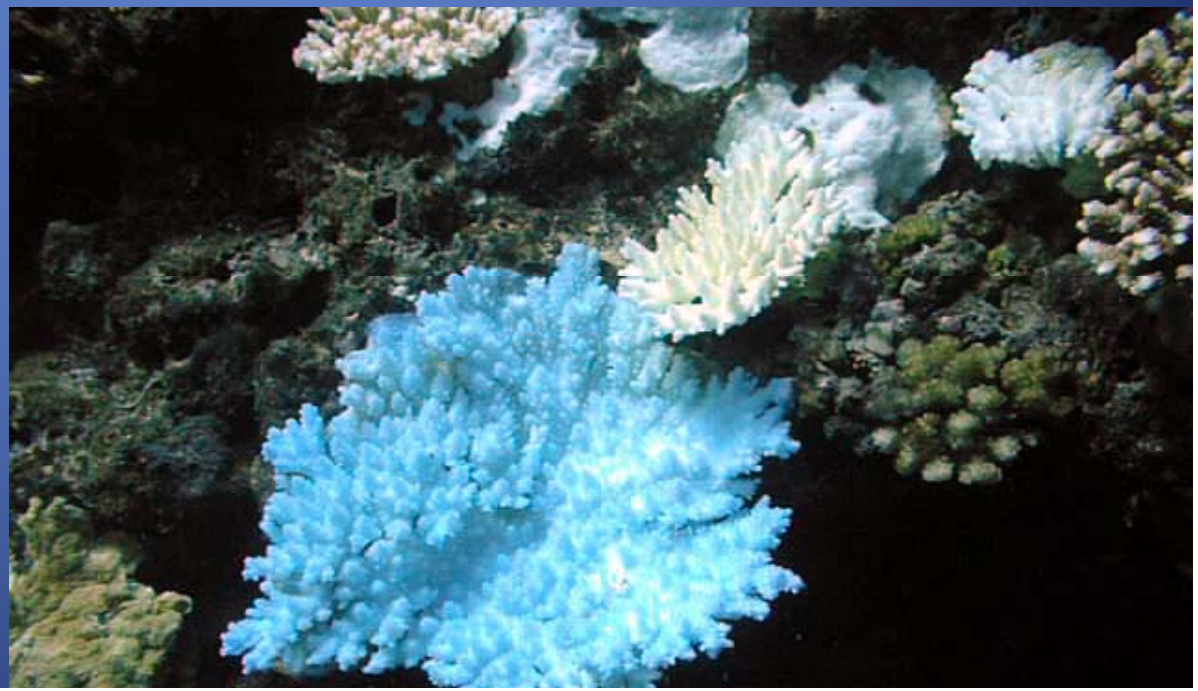
Southern Japan, 1998

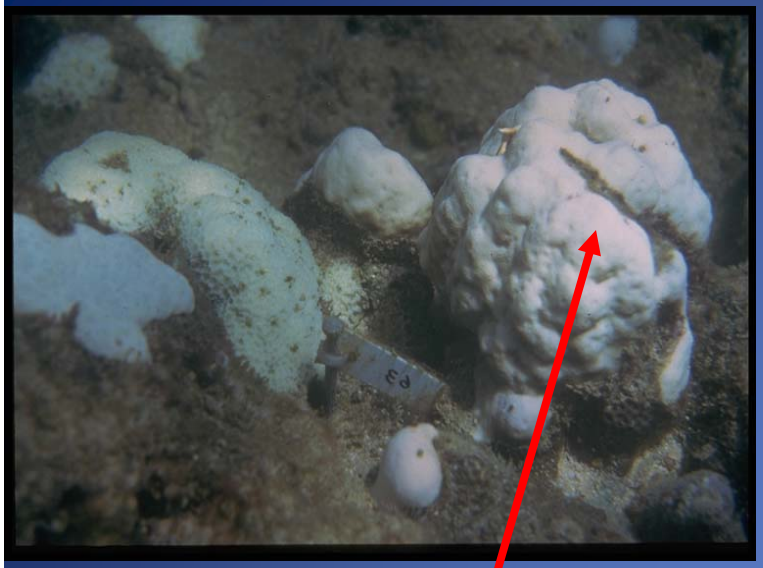
Acropora –

bleaching

& generally mortality

(14 days)





1 month

1.5 months

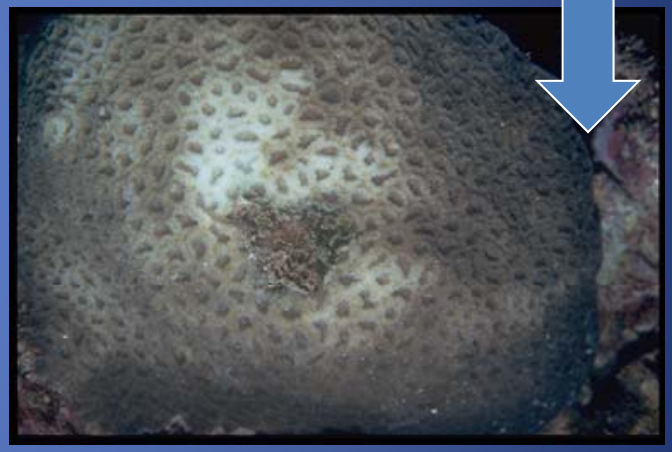
Porites lutea

2 months

van Woesik et al (2004)

2 months

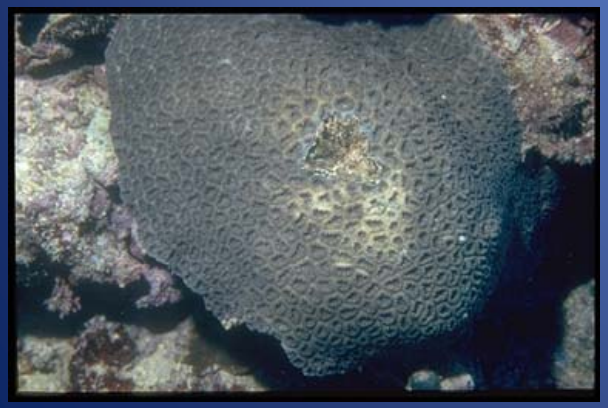
3 months



5 months

Favia favus

van Woesik R et al. (2004)



7 months

6 months

High

Tolerance

Low

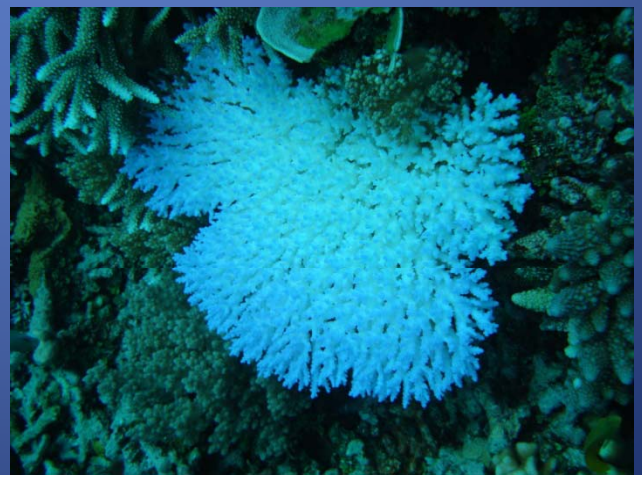
Leptastrea - Cyphastrea spp. (encrusting)

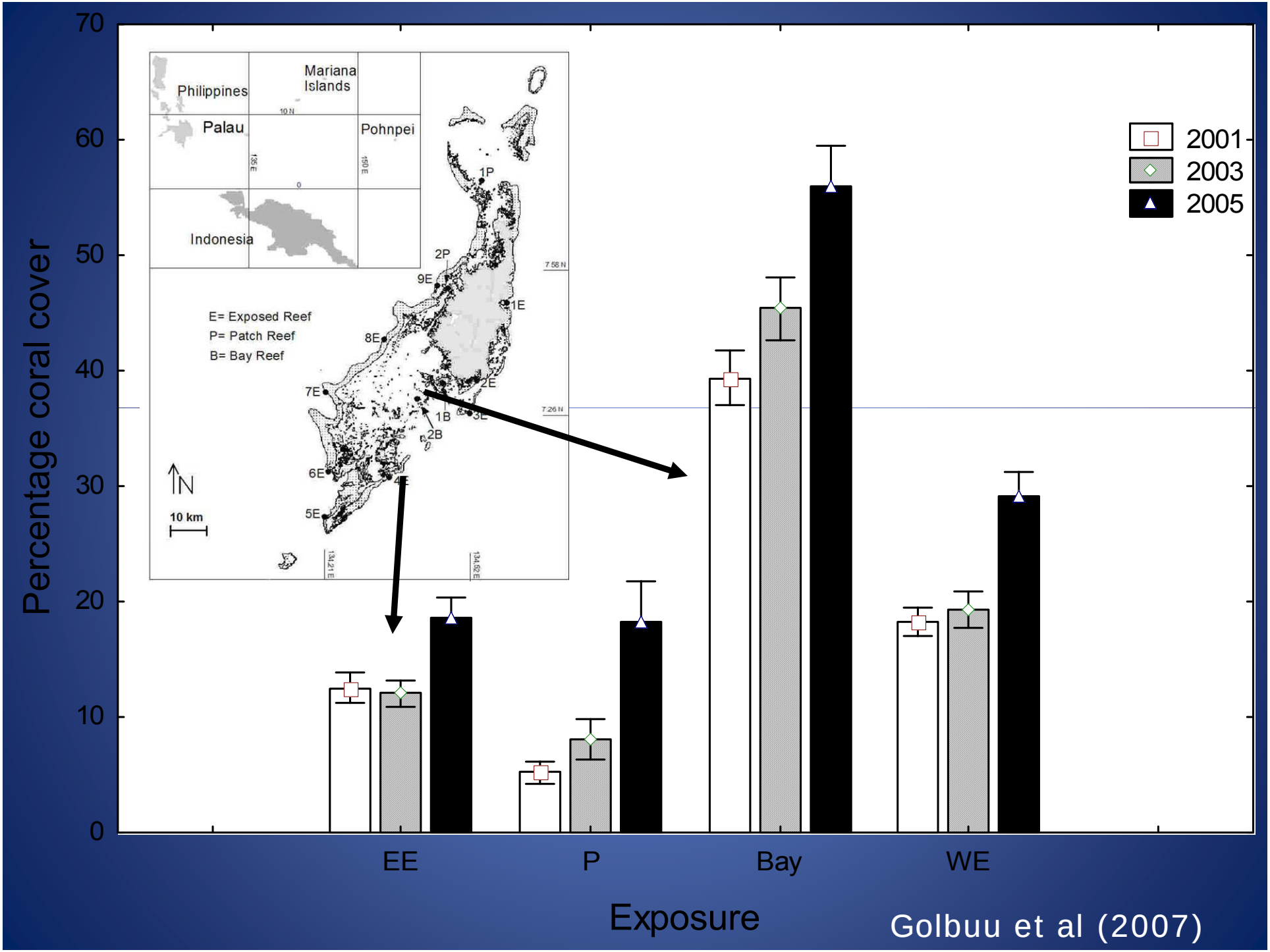
Goniastrea aspera (encrusting - massive)

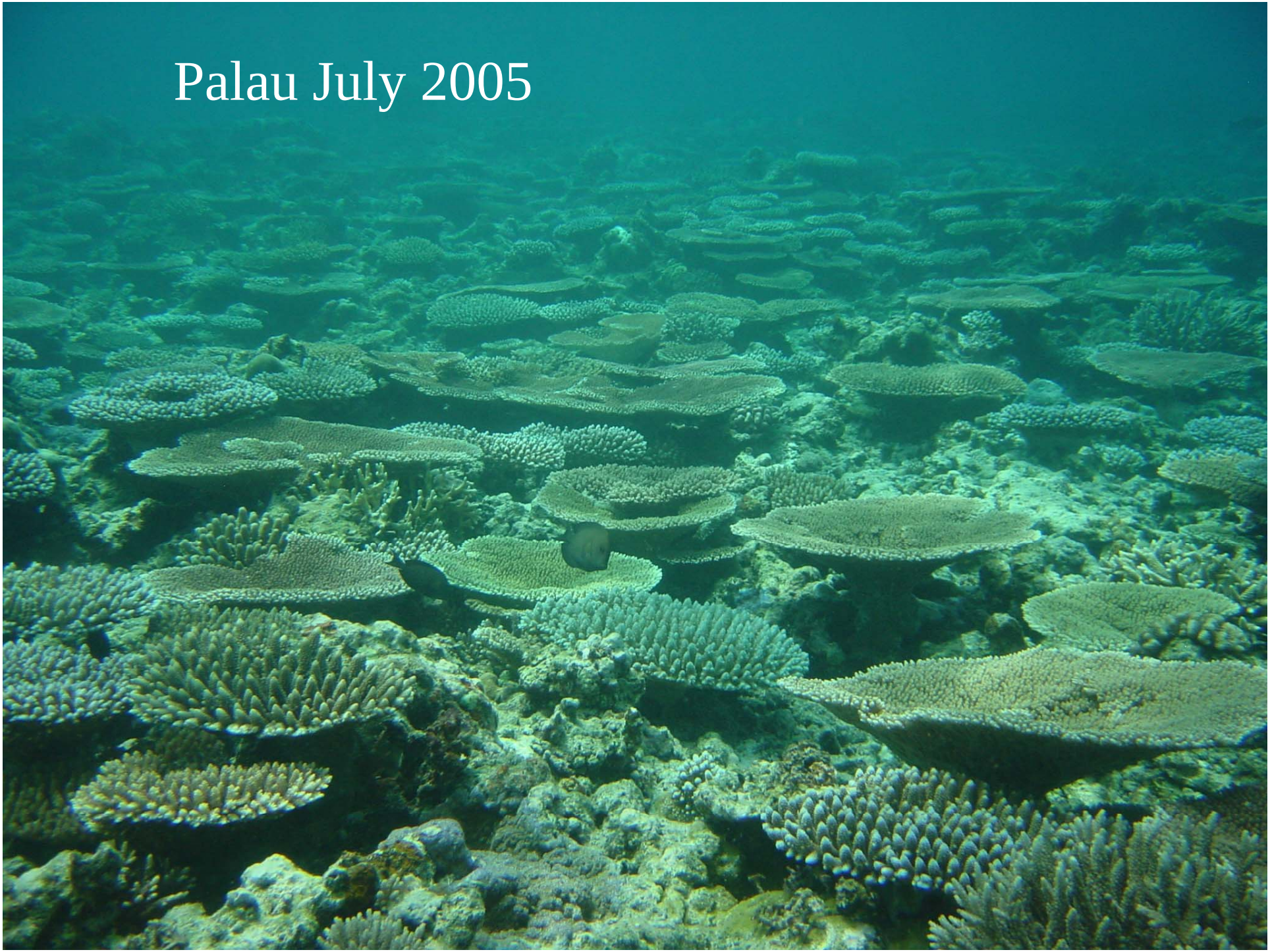
Porites lutea (massive)

Acropora spp. (branching

Pocillopora damicornis (branching)




Percentage coral cover
70
60
50
40
30
20
10
0
2001
2003
2005
EE
P
Bay
WE
Exposure
Philippines
Mariana Islands
Palau
Pohnpei
Indonesia
E= Exposed Reef
P= Patch Reef
B= Bay Reef
1P
2P
9E
1E
8E
7E
2E
3E
1B
2B
6E
4E
5E
10 km
Golbuu et al (2007)


Palau July 2005

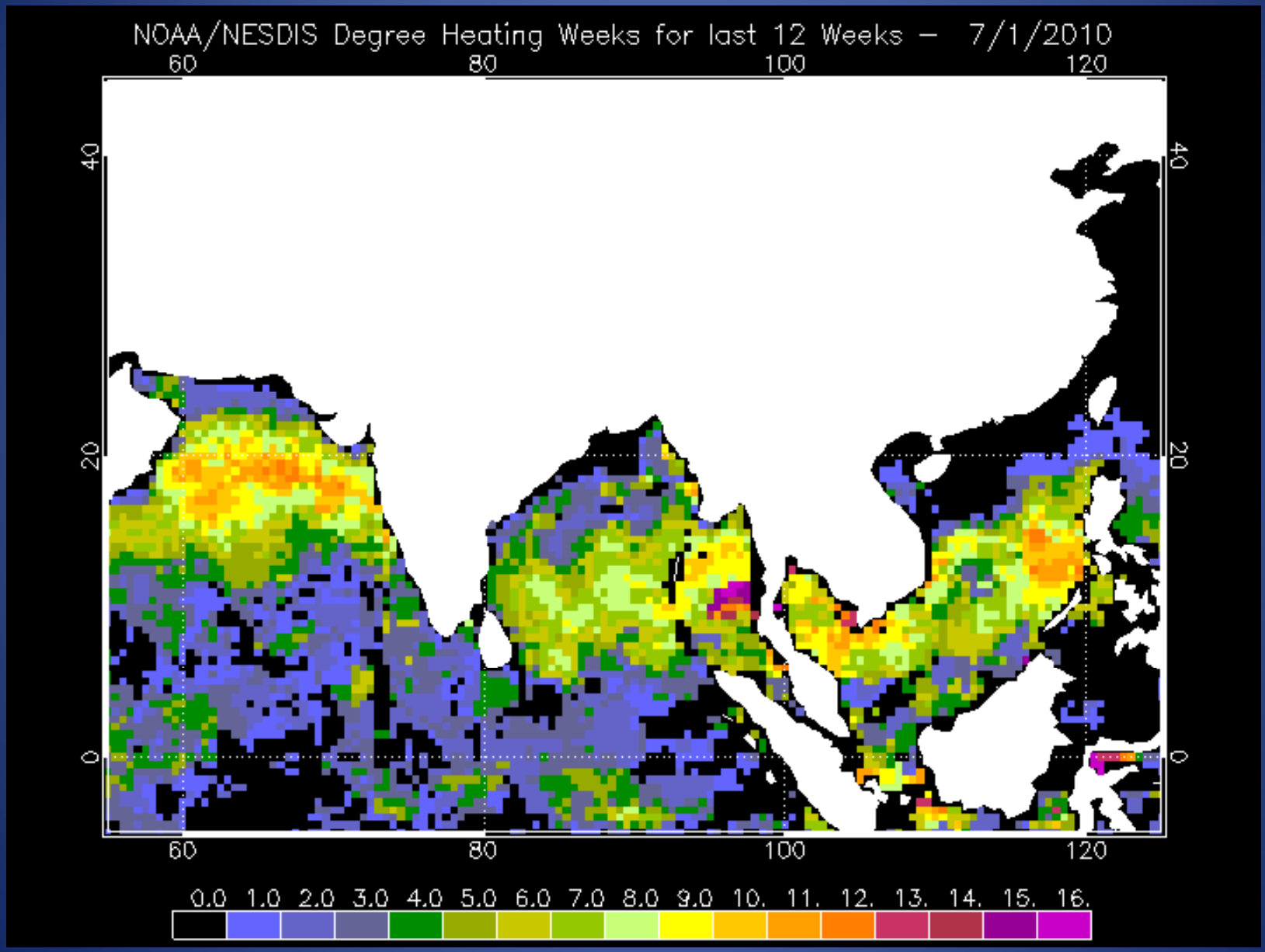
Recovery – where human influence is minimal

Old & New

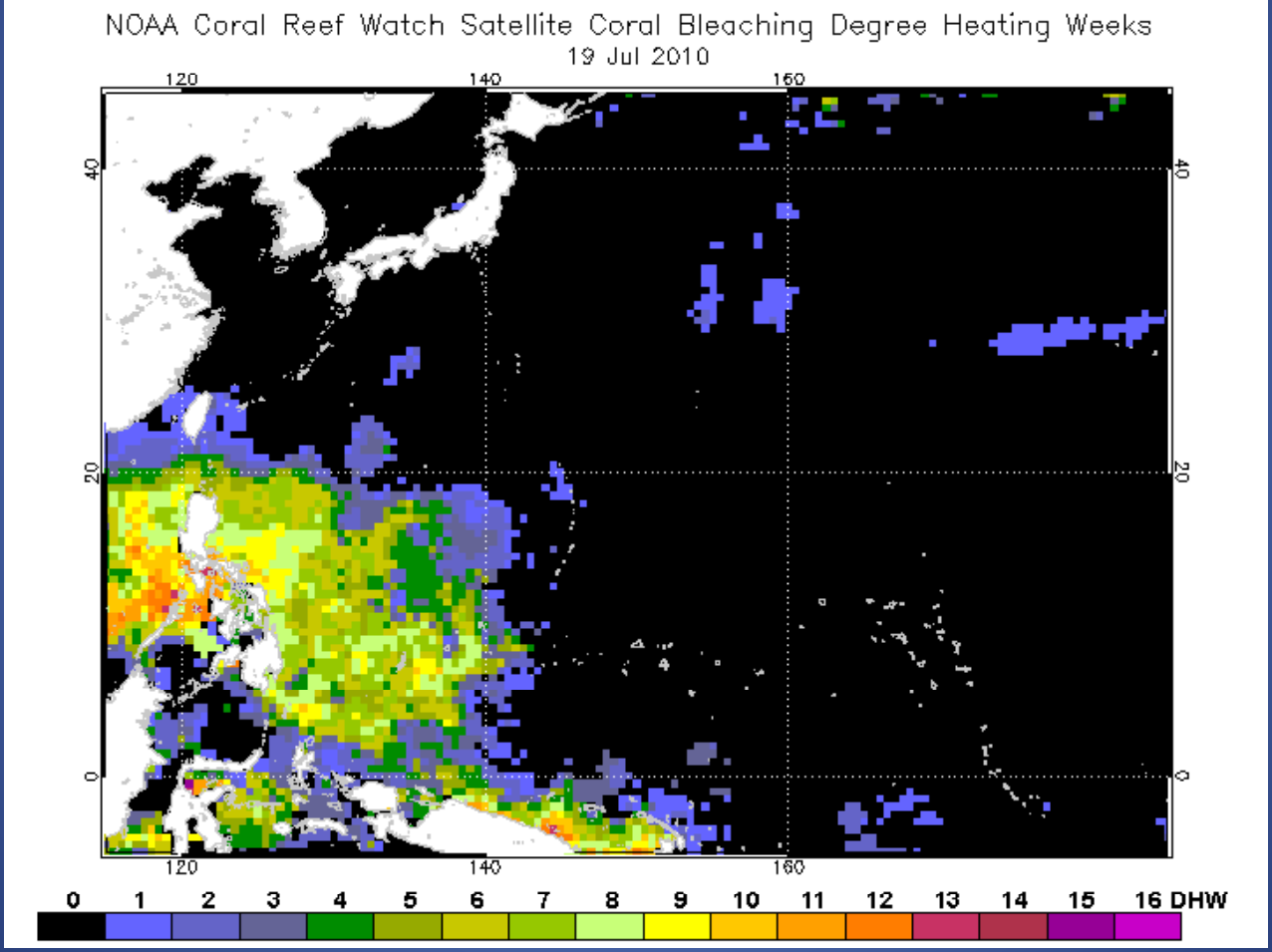
Rapid recovery

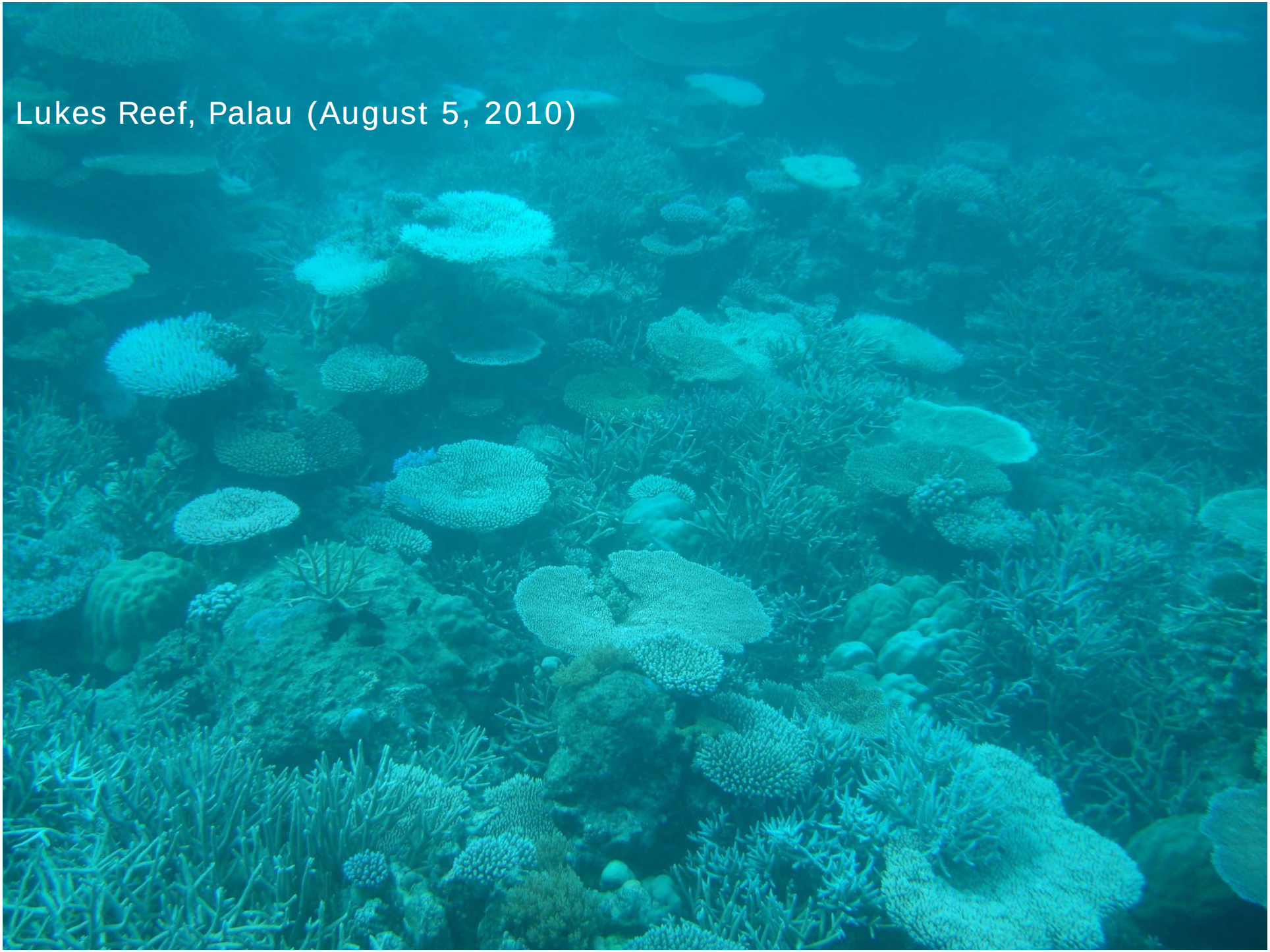
Palau, July 2005

2010


NOAA/NESDIS Degree Heating Weeks for last 12 Weeks – 7/1/2010
60
80
100
120
40
20
0
0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10. 11. 12. 13. 14. 15. 16.

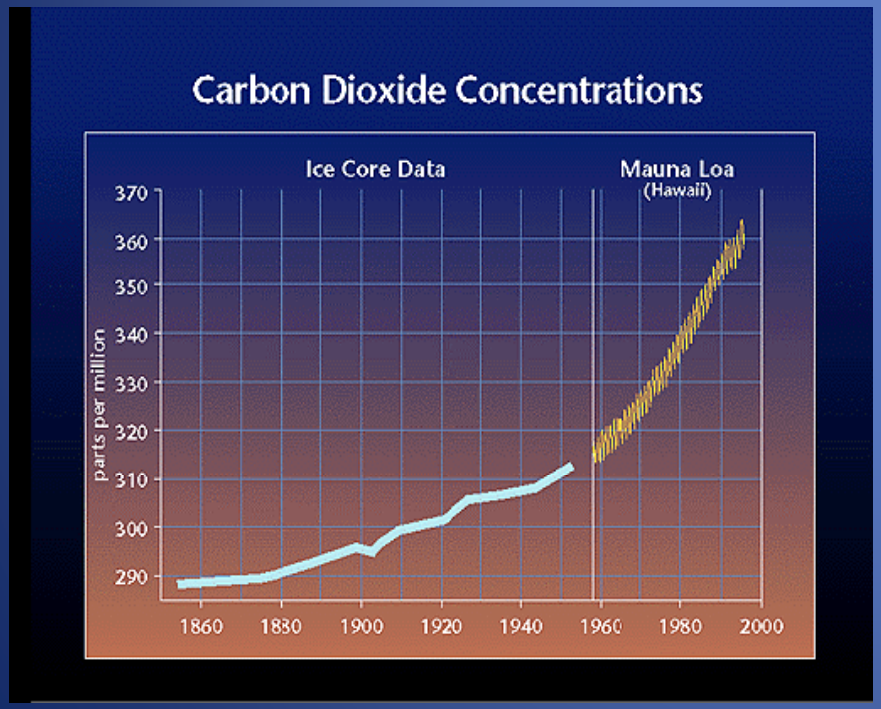
New experimental
product called the Enhanced 50km DHW product, or E50 (partial pixels)

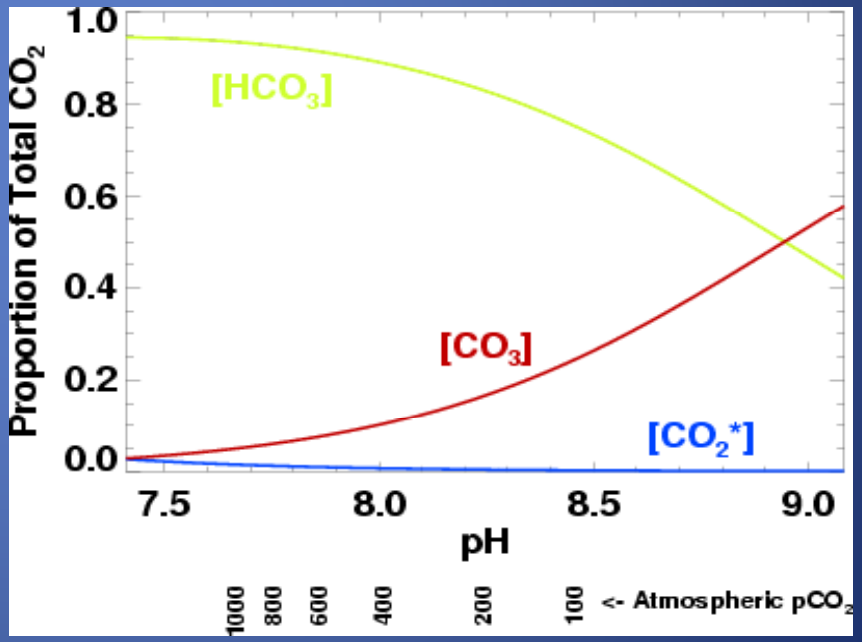


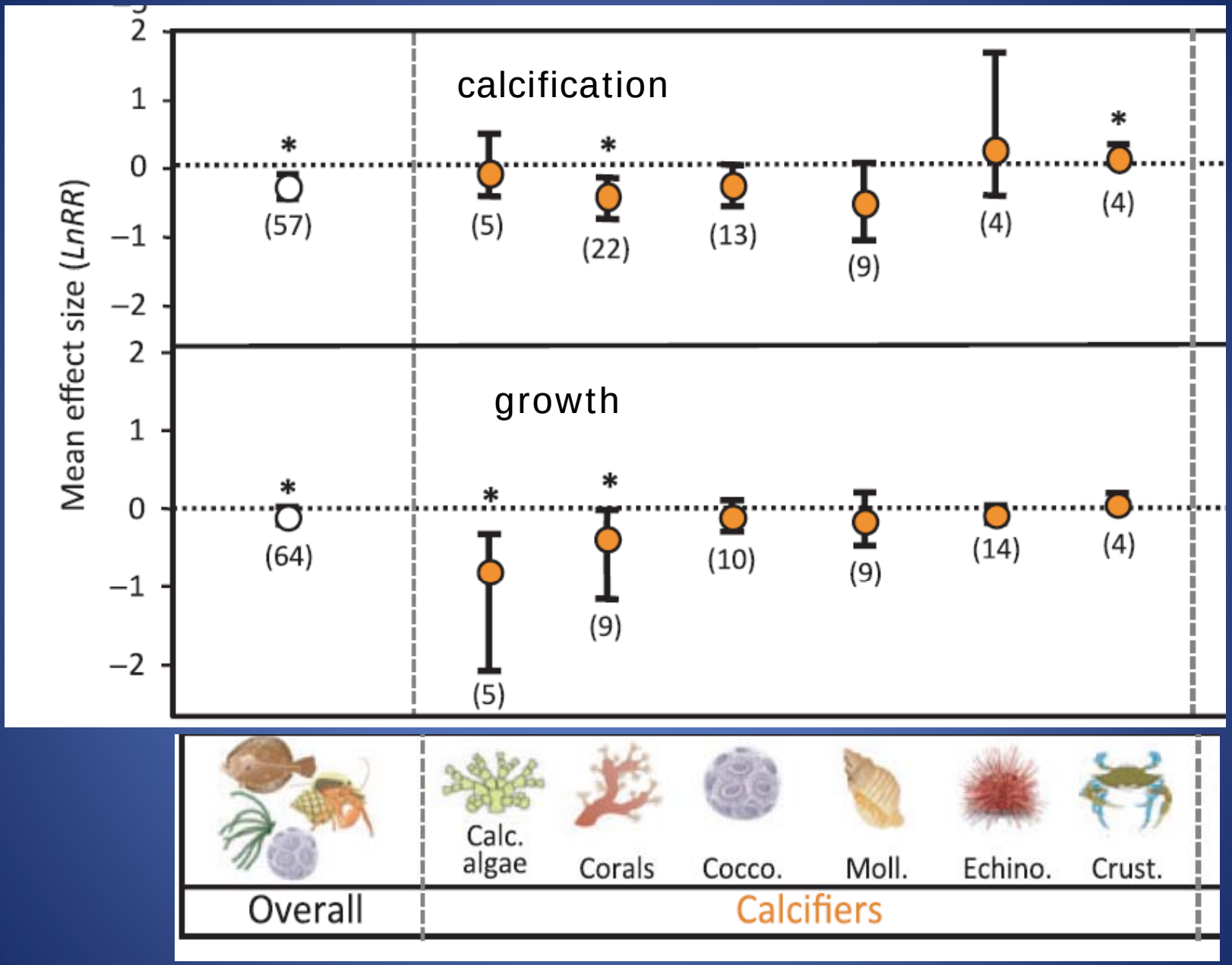

Lukes Reef, Palau (August 5, 2010)

Rising atmospheric CO_2 concentrations over the past two centuries have led to greater CO_2 uptake by the oceans.

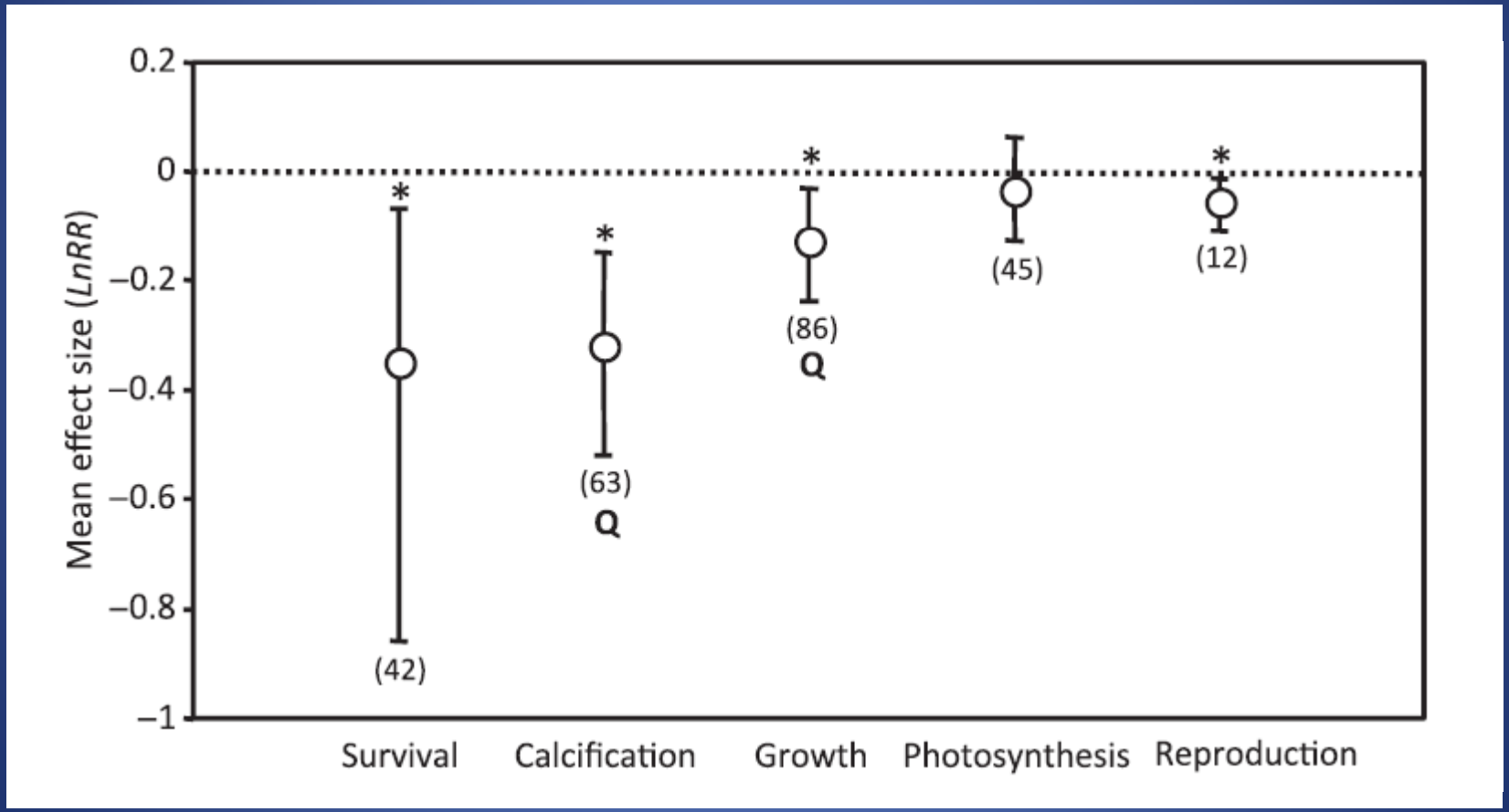
pH of seawater pH versus atmospheric CO_2



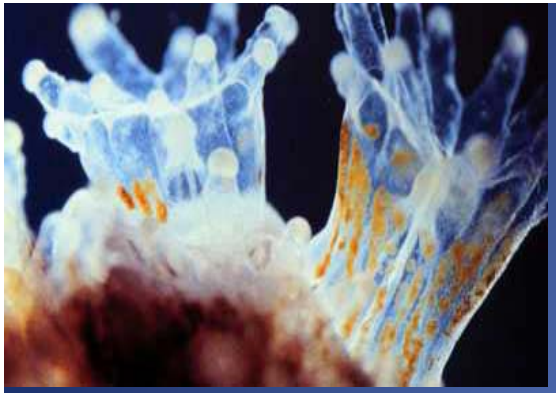


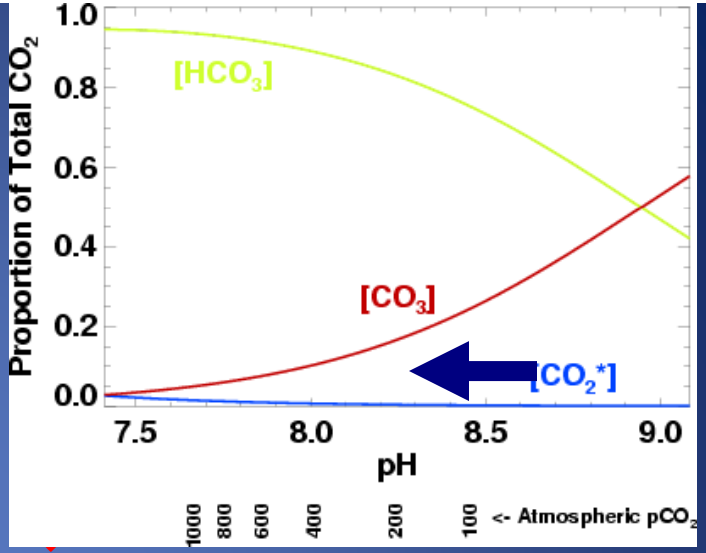


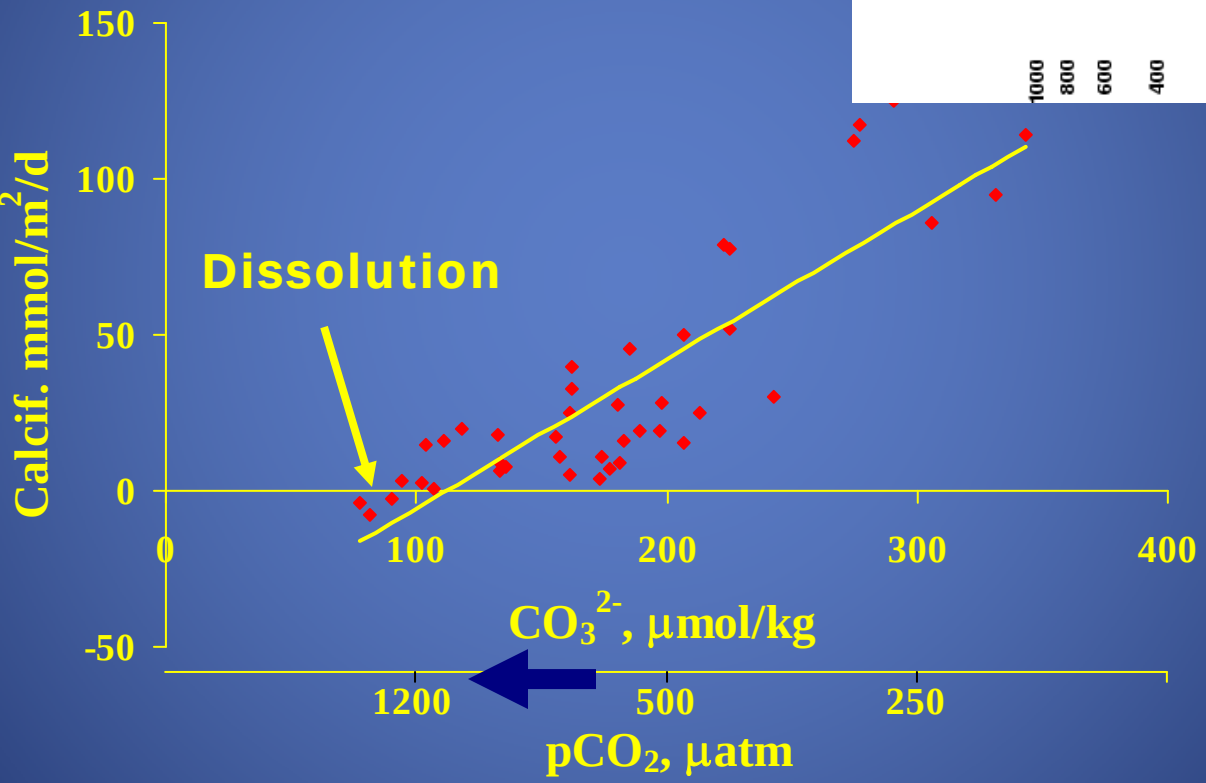
Kroeker et al (2010) Ecology Letters



Kroeker et al (2010) Ecology Letters



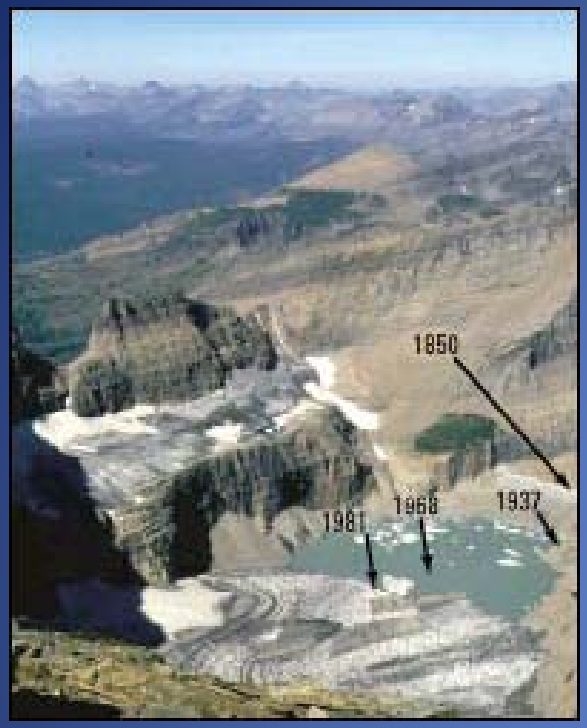


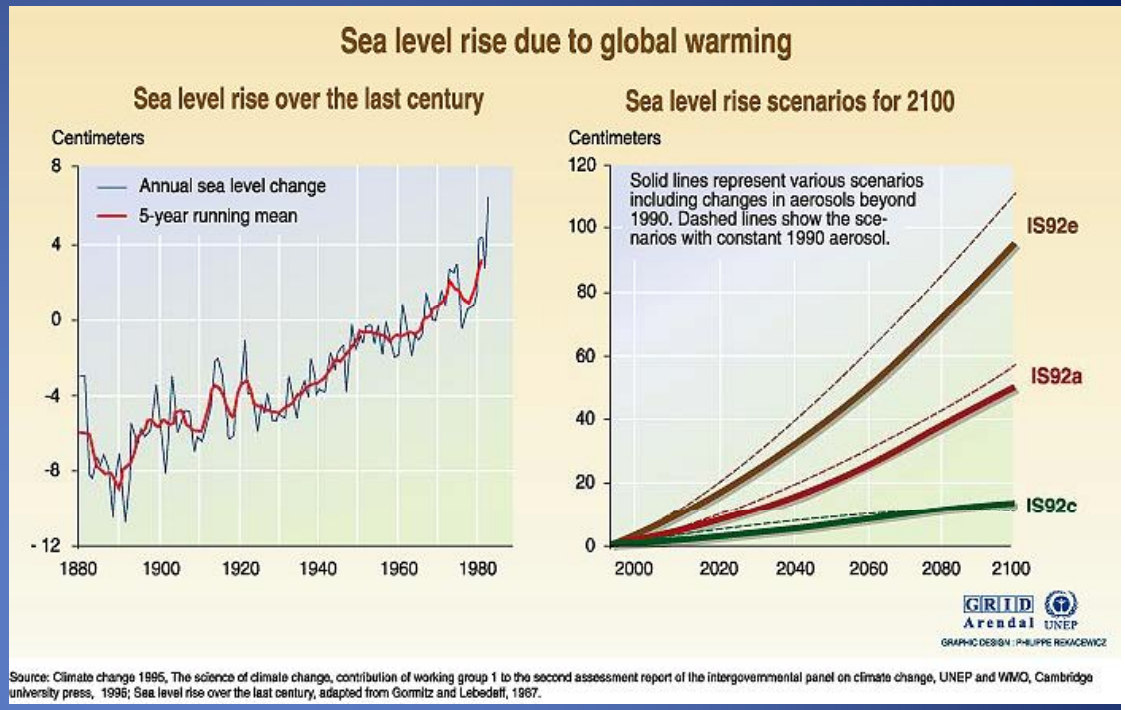


C. Langdon & Atkinson

CO_2 - rate of change !

- "The rate of change is 100 times faster than anything seen in the past hundreds of millennia"
  Nature (2006) 442: 978-980

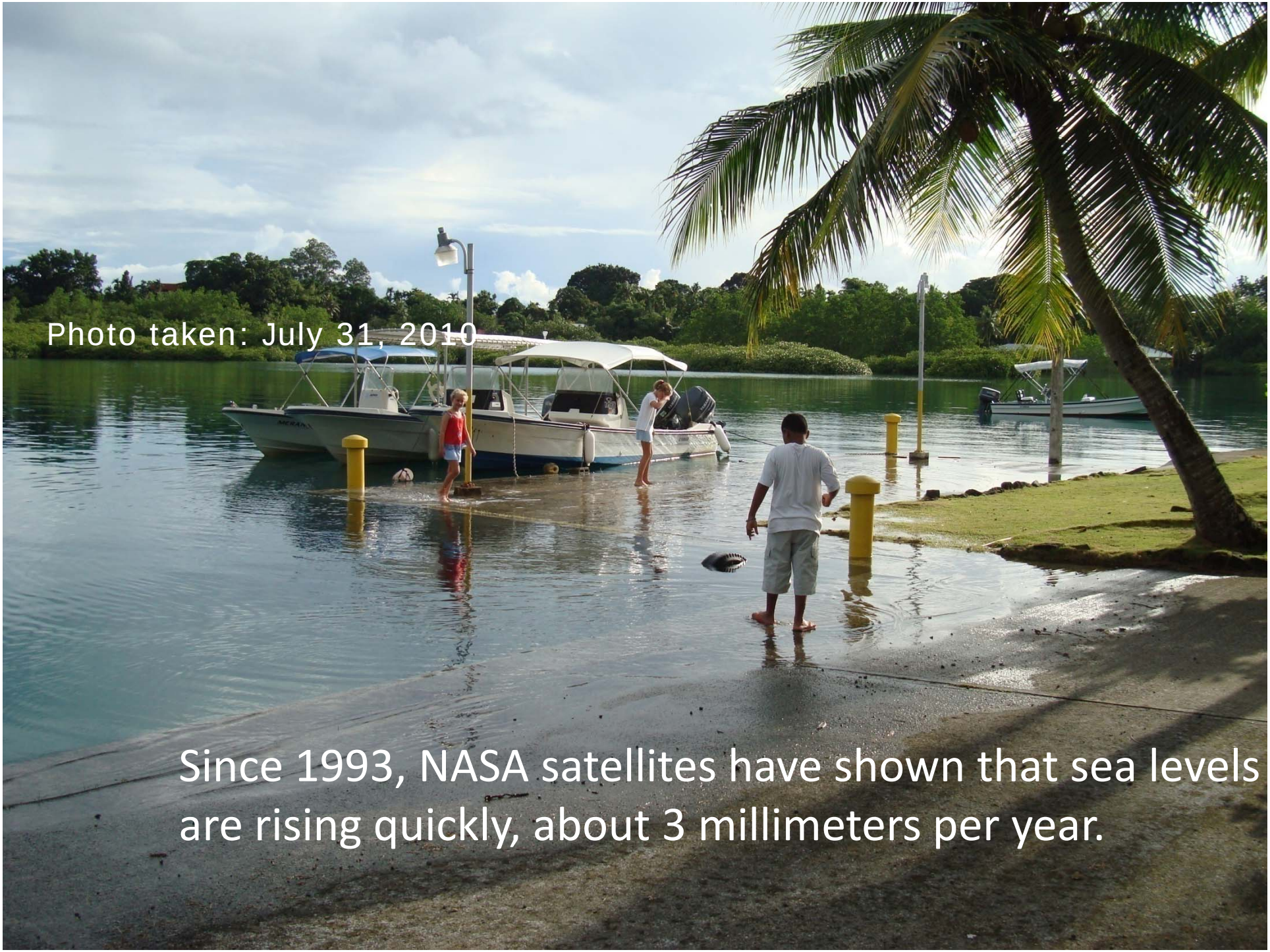




Source: Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996; Sea level rise over the last century, adapted from Gornitz and Lebedeff, 1987.

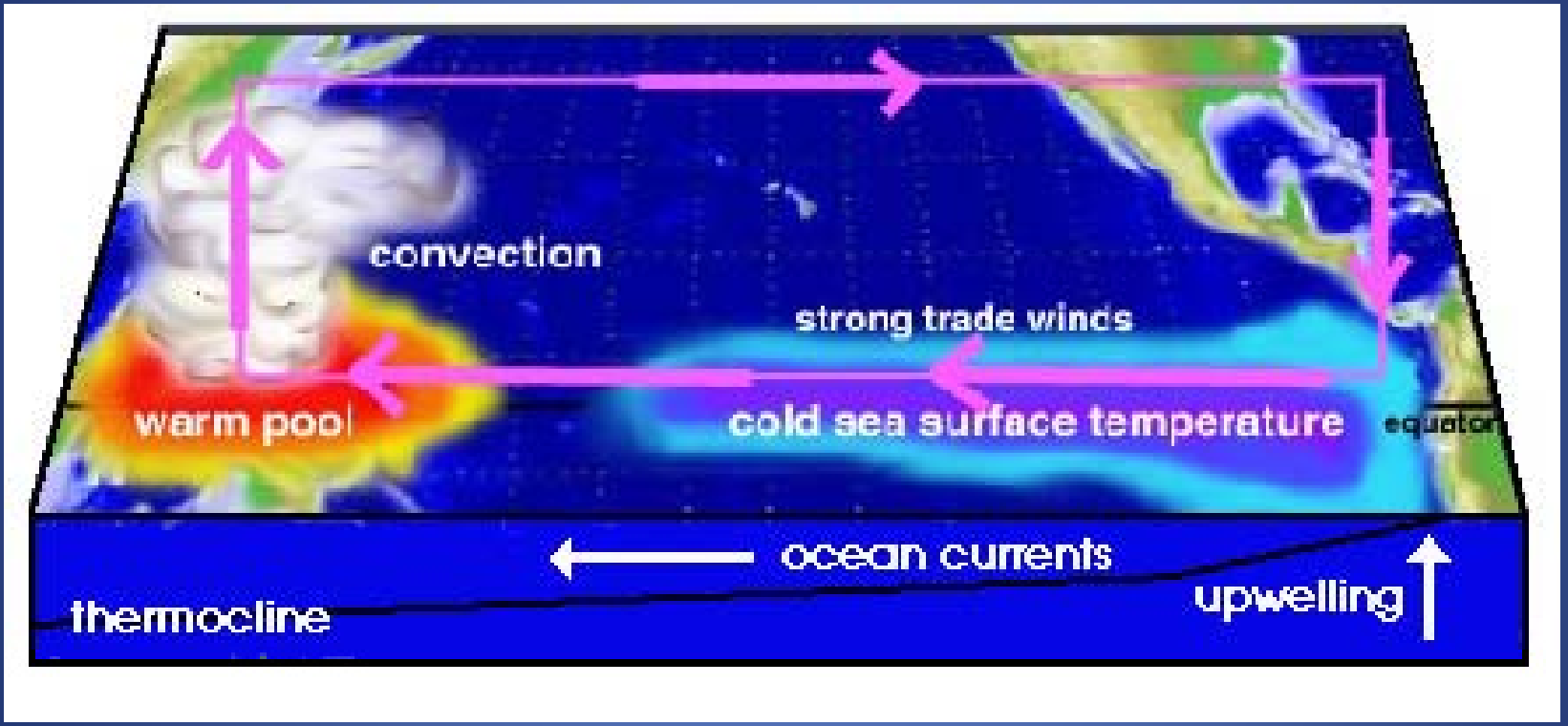
Sea-level rise over the next 50 years:

Conservative – 10 cm
Probably - 20 cm
At worst – 50 cm

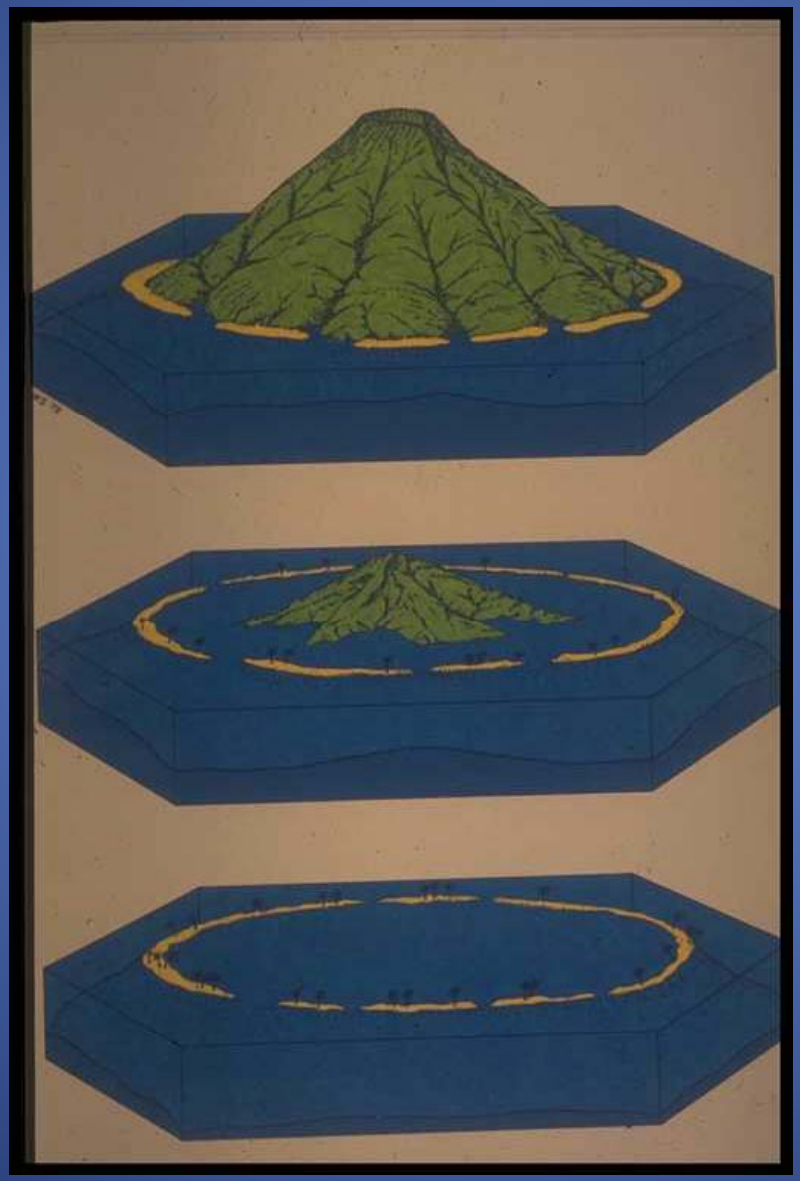


Since 1993, NASA satellites have shown that sea levels are rising quickly, about 3 millimeters per year.

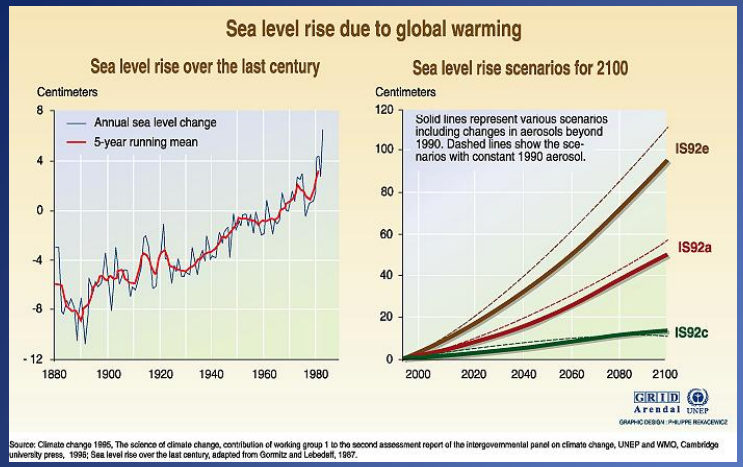
La Nina


convection
strong trade winds
warm pool
cold sea surface temperature
equator
ocean currents
thermocline
upwelling

Modal coral-reef growth: 4 kg/m^2. yr , or about 5 mm/yr of upward growth if all carbonate is retained.



Darwin 1842

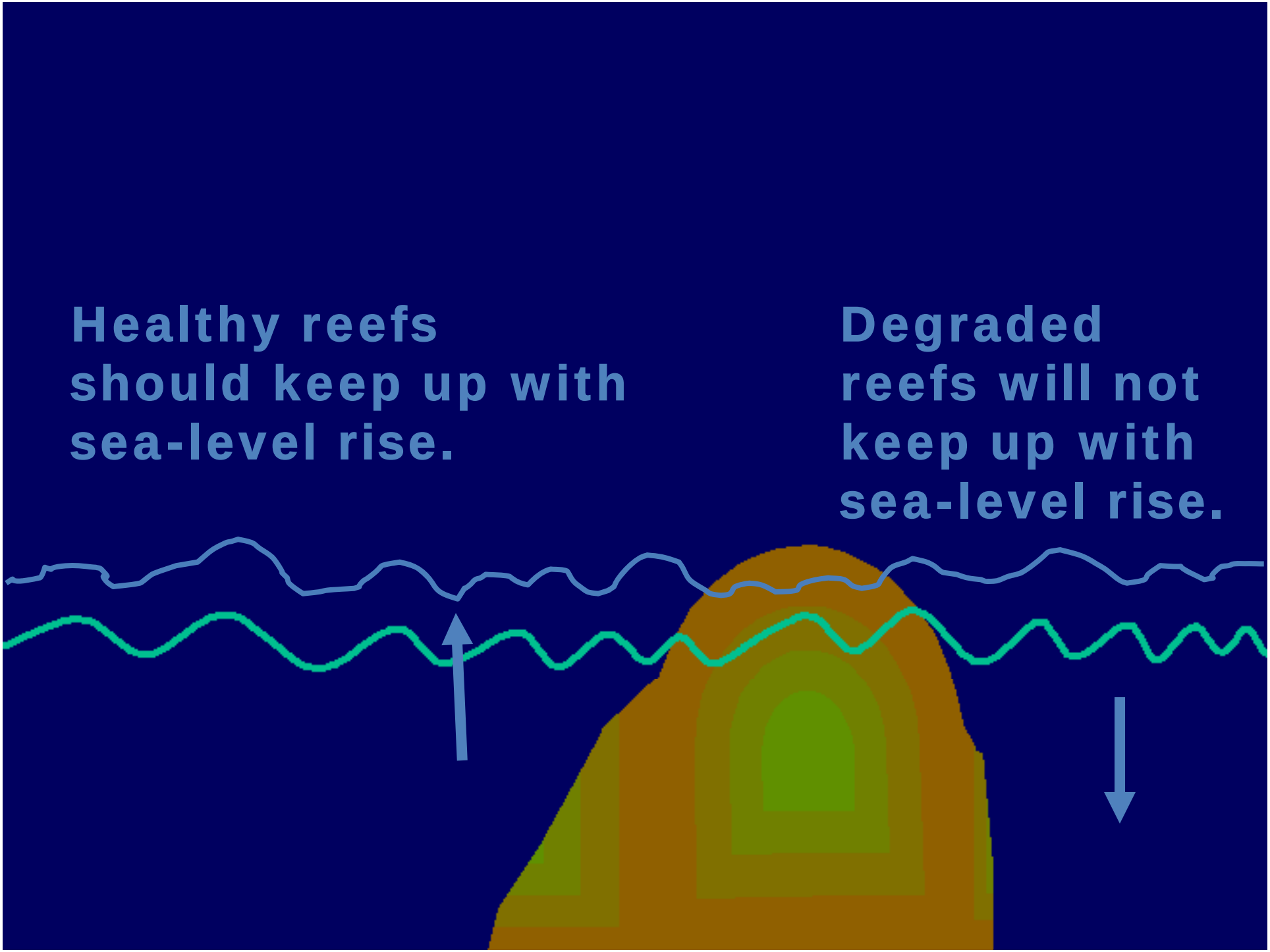


Sea-level rise over the next 50 years:

Conservative – 10 cm (2 mm/yr)
Probably - 20 cm (4 mm/yr)
At worst – 50 cm (10 mm/yr)

Modal coral-reef growth:

~ 5 mm/yr of upward growth if all carbonate is retained.


Healthy reefs
should keep up with
sea-level rise.
Degraded
reefs will not
keep up with
sea-level rise.

Therefore, we need to know the state of the reefs in Micronesia.

First (take home message 1);

We need a comprehensive monitoring program for Micronesia.

TRUK ISLANDS

FROM THE JAPANESE GOVERNMENT CHARTS TO 1943

With additions from the United States Government Charts to 1974.

For Symbols and Abbreviations see Admiralty Chart 5011.

All Heights are expressed in Feet above Mean Higher High Water

SOUNDINGS in FATHOMS
(Under Elevan in Fathoms and Feet)

Projection - Mercator

NATURAL SCALE 1:125,000 (at Lat. 7°20')

IALA Maritime Buoyage System
Region A (Red to port)

CAUTIONS

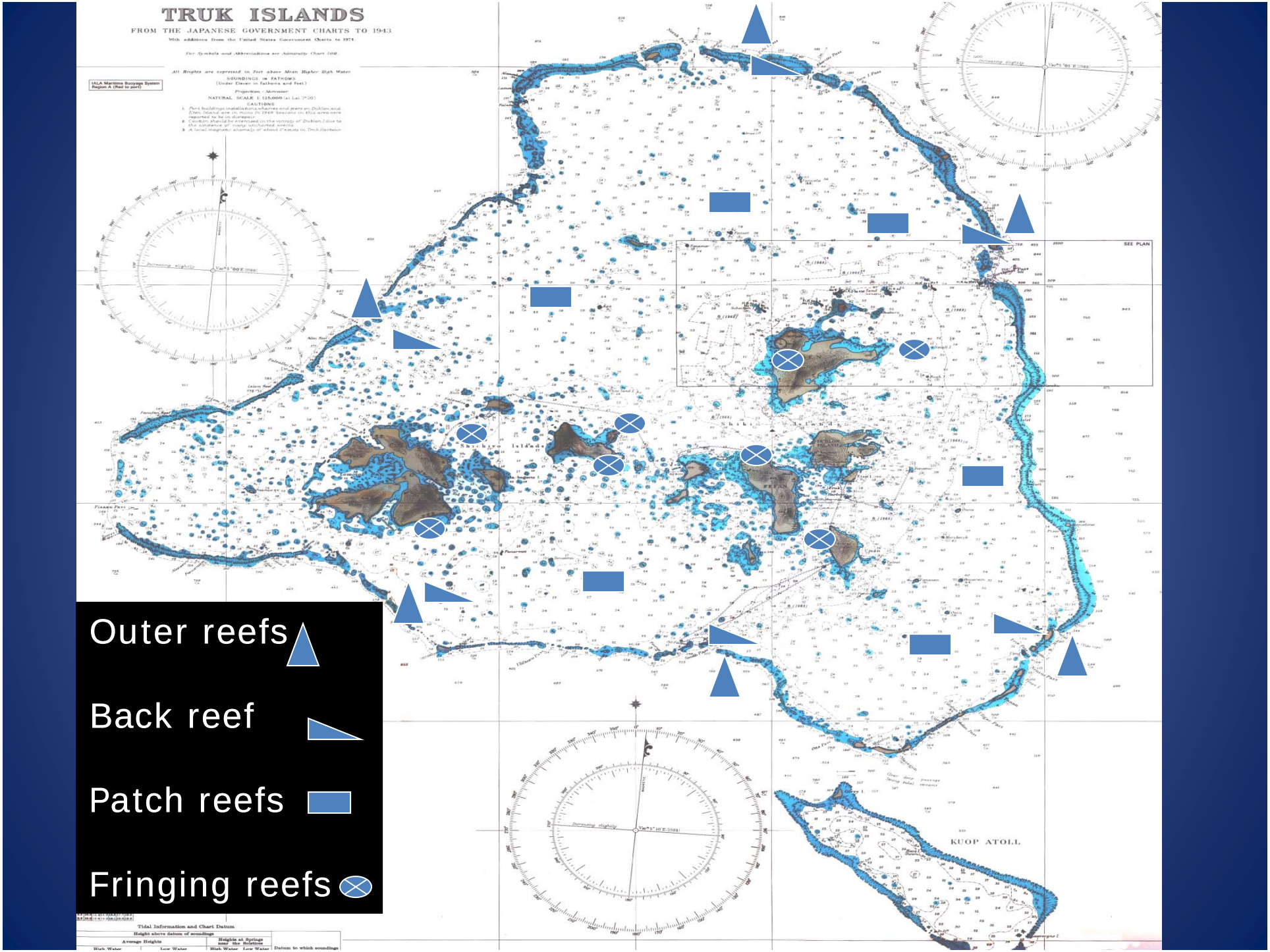
1. Port buildings installations,wharves and piers on Dublon and Eten Island are in ruins.In 1969 beacons in this area were reported to be in disrepair.
2. Caution should be exercised in the vicinity of Dublon,due to the existence of many uncharted wrecks.
3. A local magnetic anomaly of about 2°easts in Truk Harbour

SEE PLAN

KUOP ATOLL

Tidal Information and Chart Datum

Height above datum of soundings				
Average Heights		Heights at Springs near the Solstices		Datum to which soundings
High Water	Low Water	High Water	Low Water	


TRUK ISLANDS
FROM THE JAPANESE GOVERNMENT CHARTS TO 1943
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SOUNDINGS in FATHOMS
(Under Eleven in fathoms and Feet)
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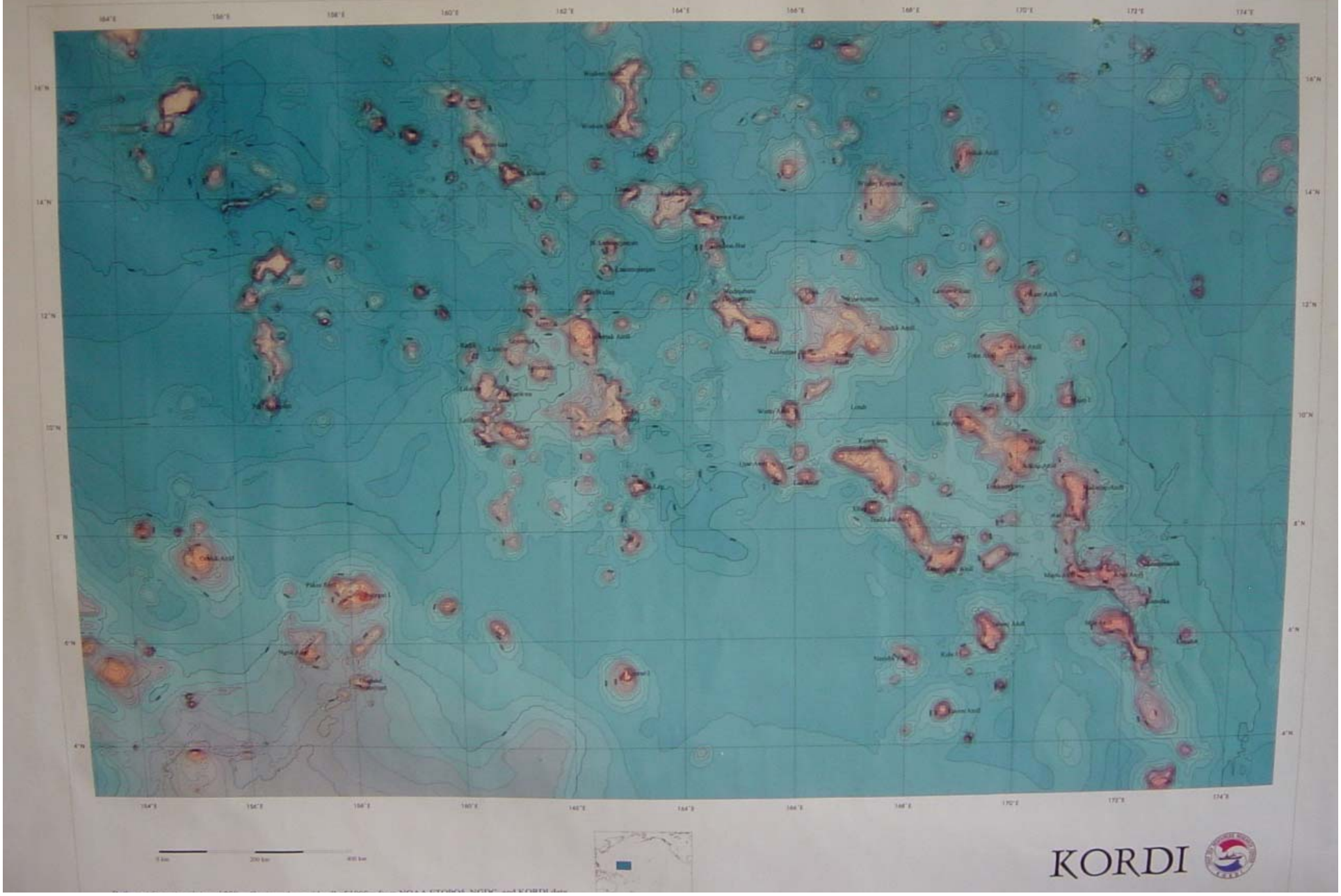
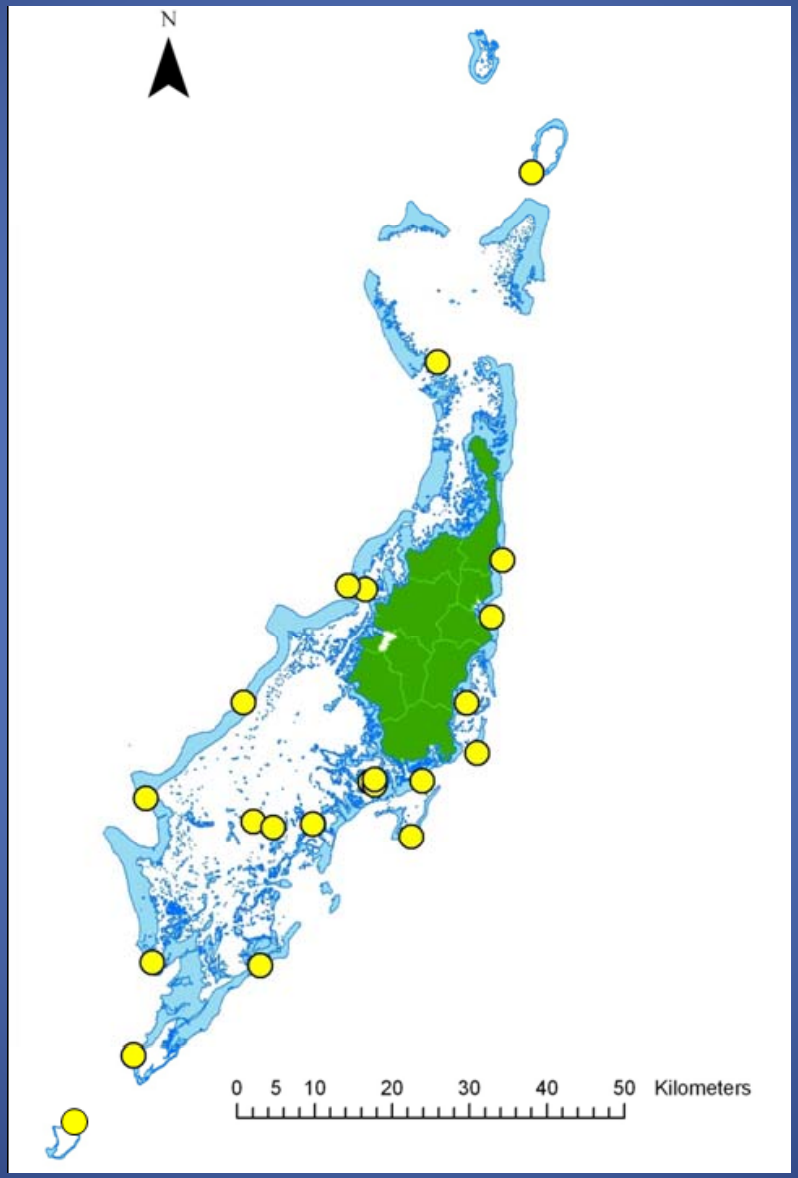
NATURAL SCALE 1:125,000 (at Lat. 7°20')
CAUTIONS
IALA Maritime Buoyage System
Region A (Red to port)
SEE PLAN
KUOP ATOLL
Outer reefs
Back reef
Patch reefs
Fringing reefs
Tidal Information and Chart Datum
Height above datum of soundings
Average Heights
Heights at Springs near the Solstices
High Water
Low Water
High Water
Low Water
Datum to which soundings

Republic of the Marshall Islands

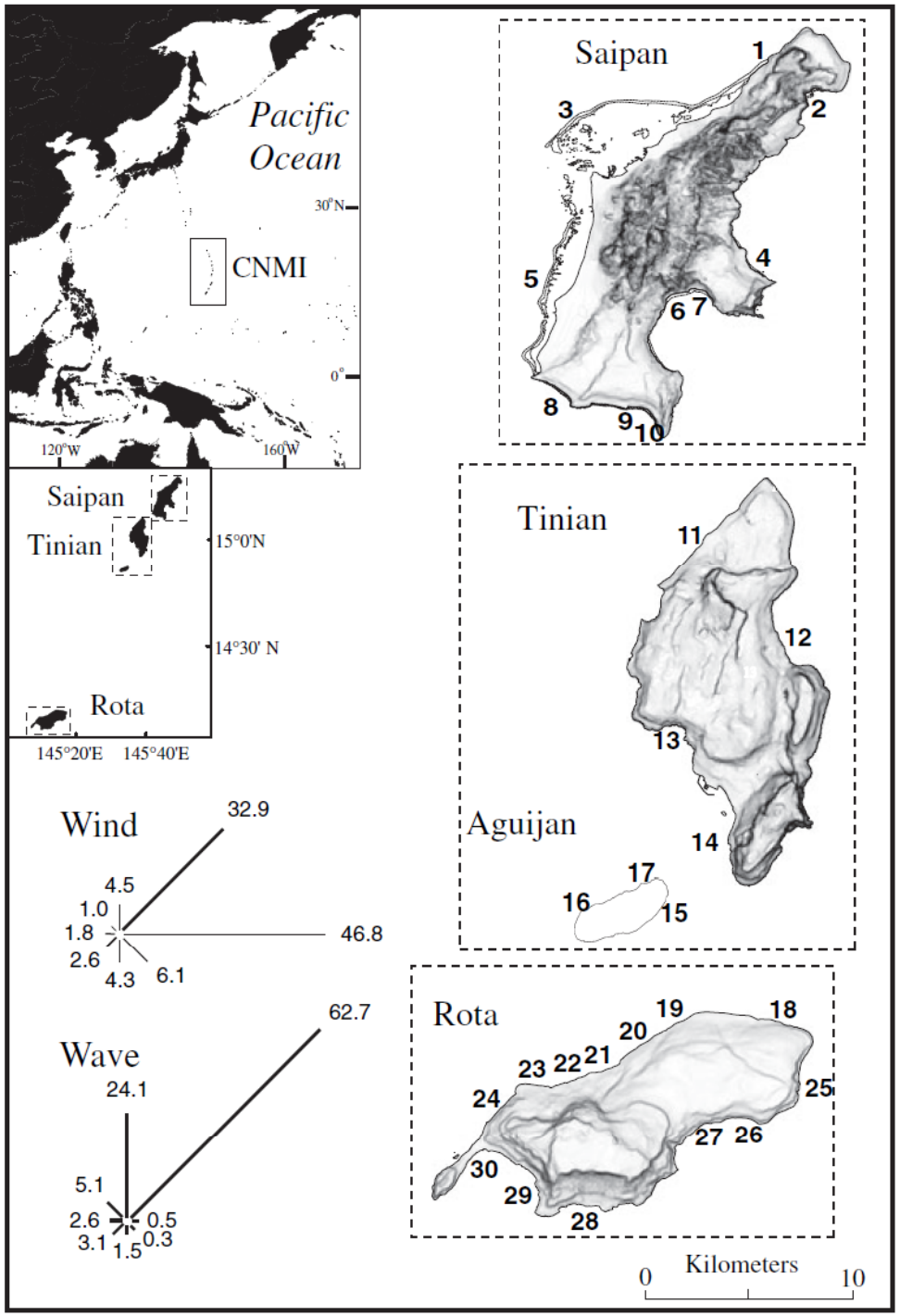


KORDI

Palau – 22 monitoring sites



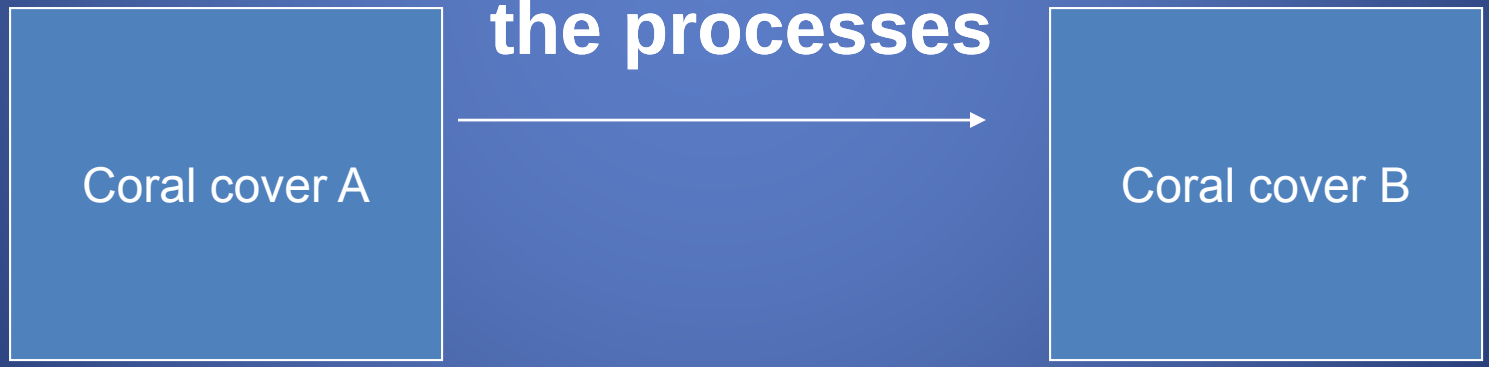
Golbuu et al (2007)

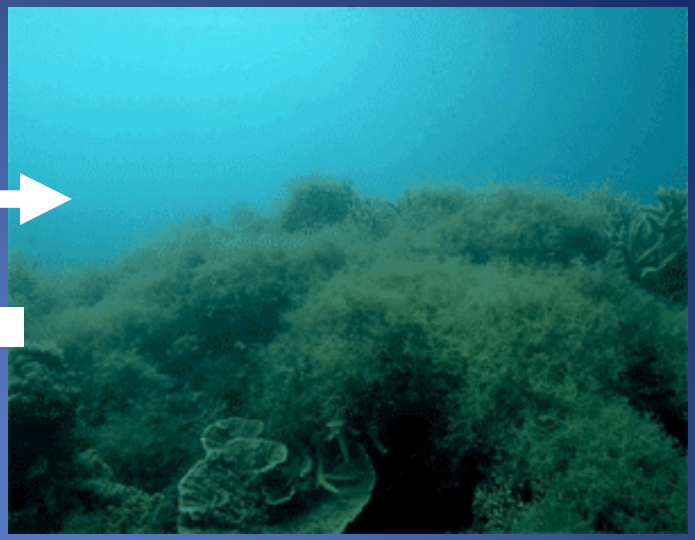


Houk and van Woesik (2009)
Marine Ecology 31: 318-329

Even the best monitoring programs need an upgrade…

We need to understand the processes





We need to understand the processes

Coral cover A

Connectivity
Recruitment
Post-settlement mortality
Growth
Healing
Fragmentation
Mortality

Coral cover B

Population Processes

Recruitment

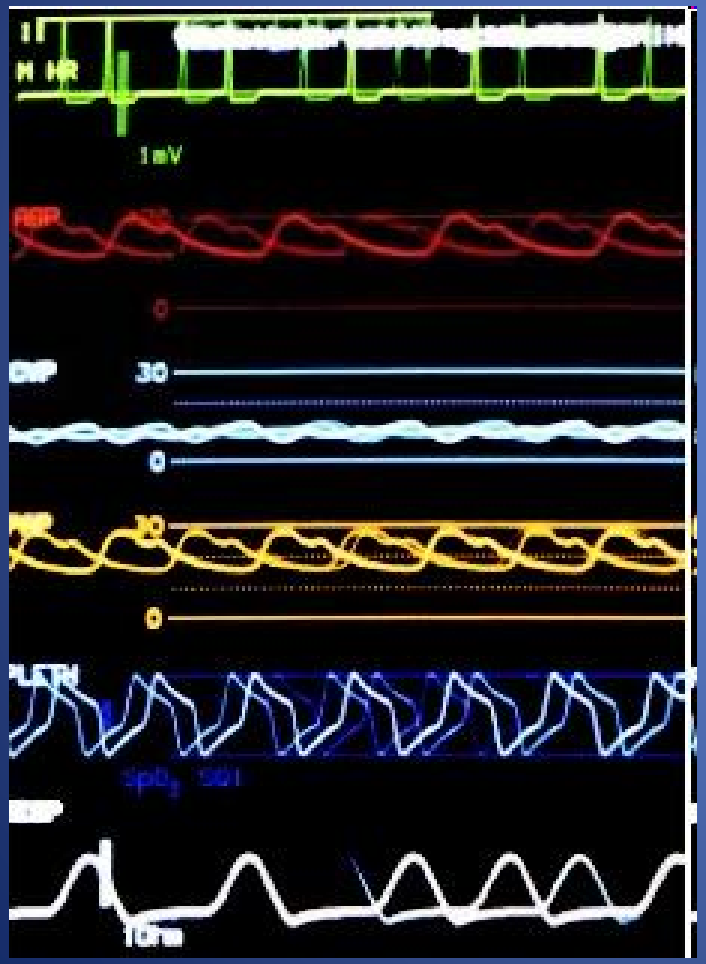
Post-settlement mortality

Growth

Partial Mortality

Total Mortality

Vital rates (signs)



Heart rate

Arterial blood pressure (ABP)

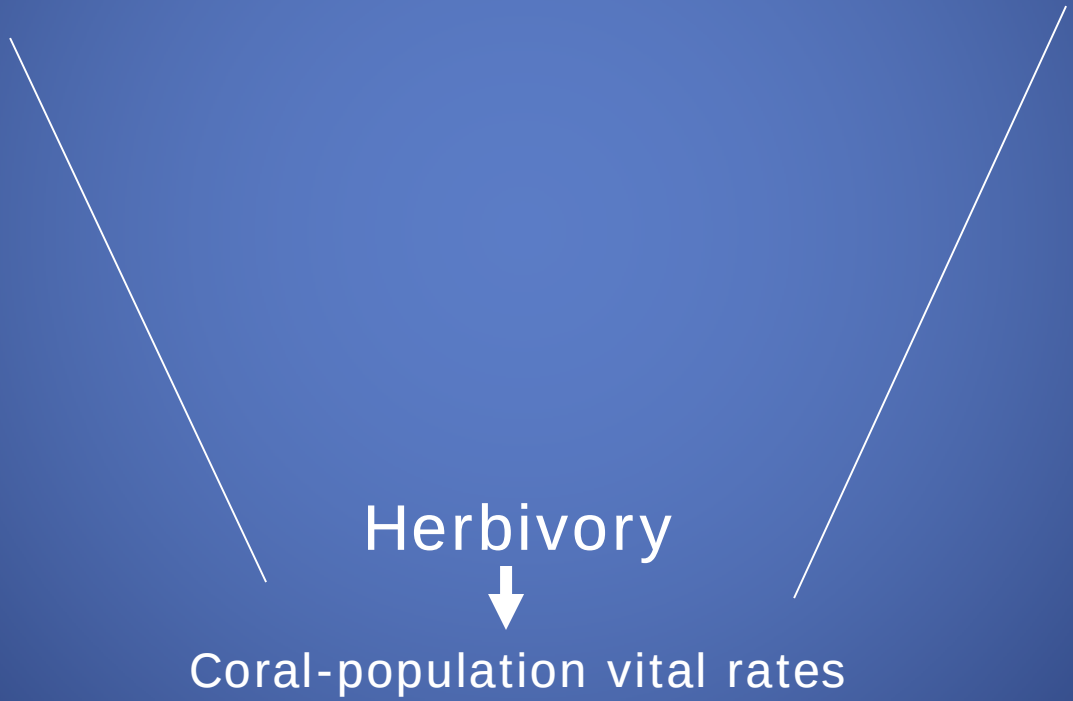
Central venous pressure (CVP)

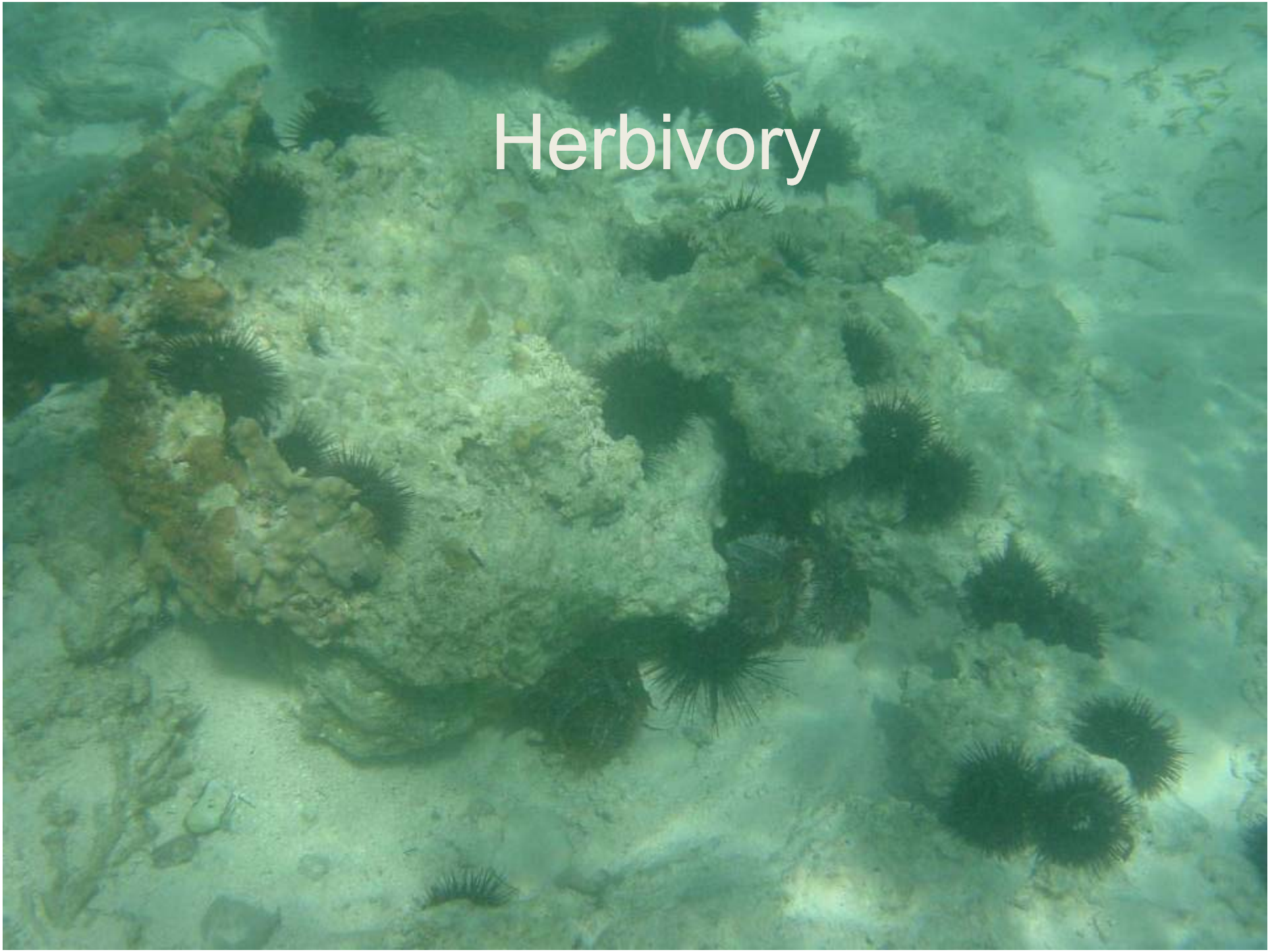
Pulmonary artery pressure (PAP)

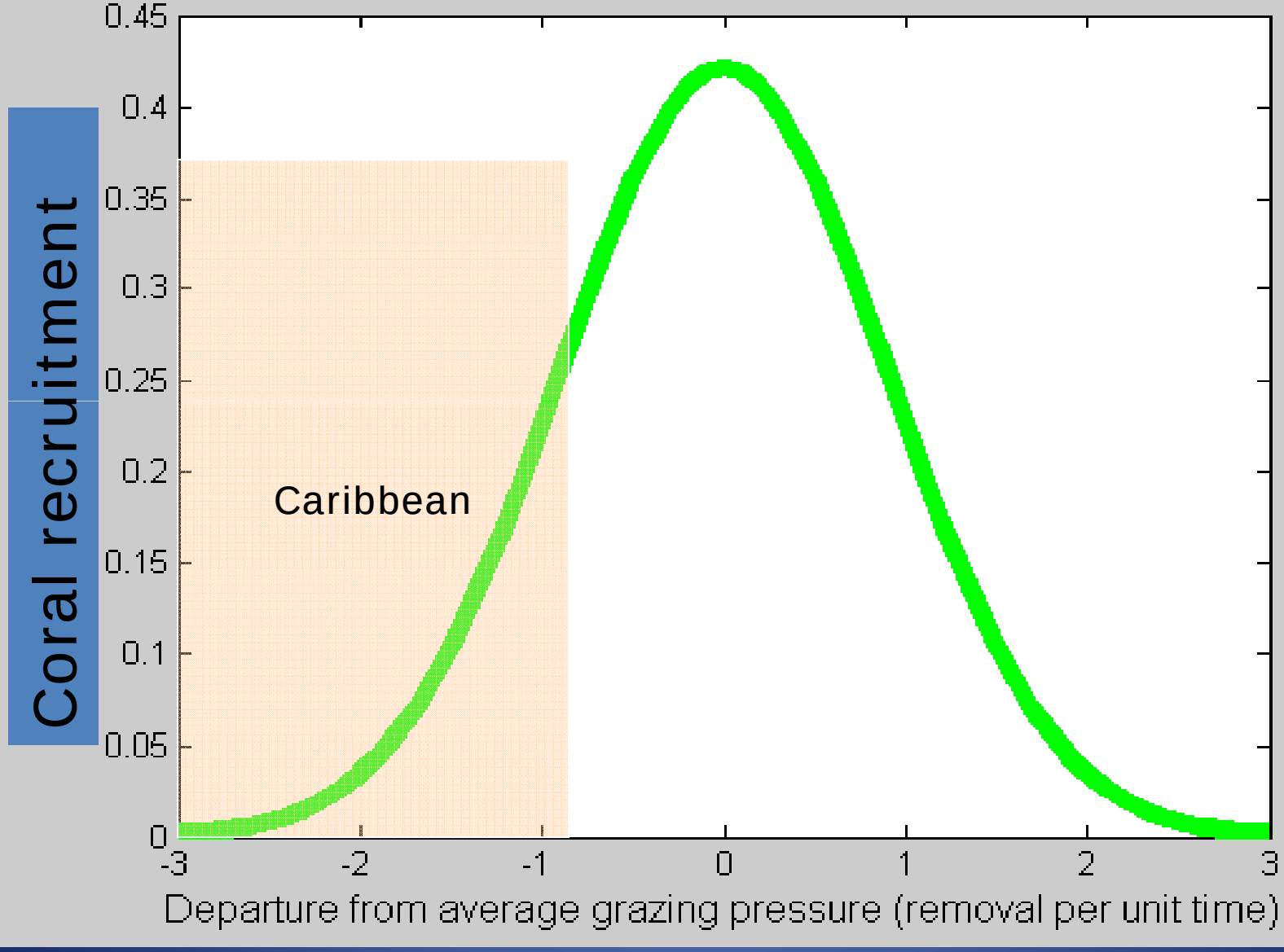
Blood oxygen (PLETH)

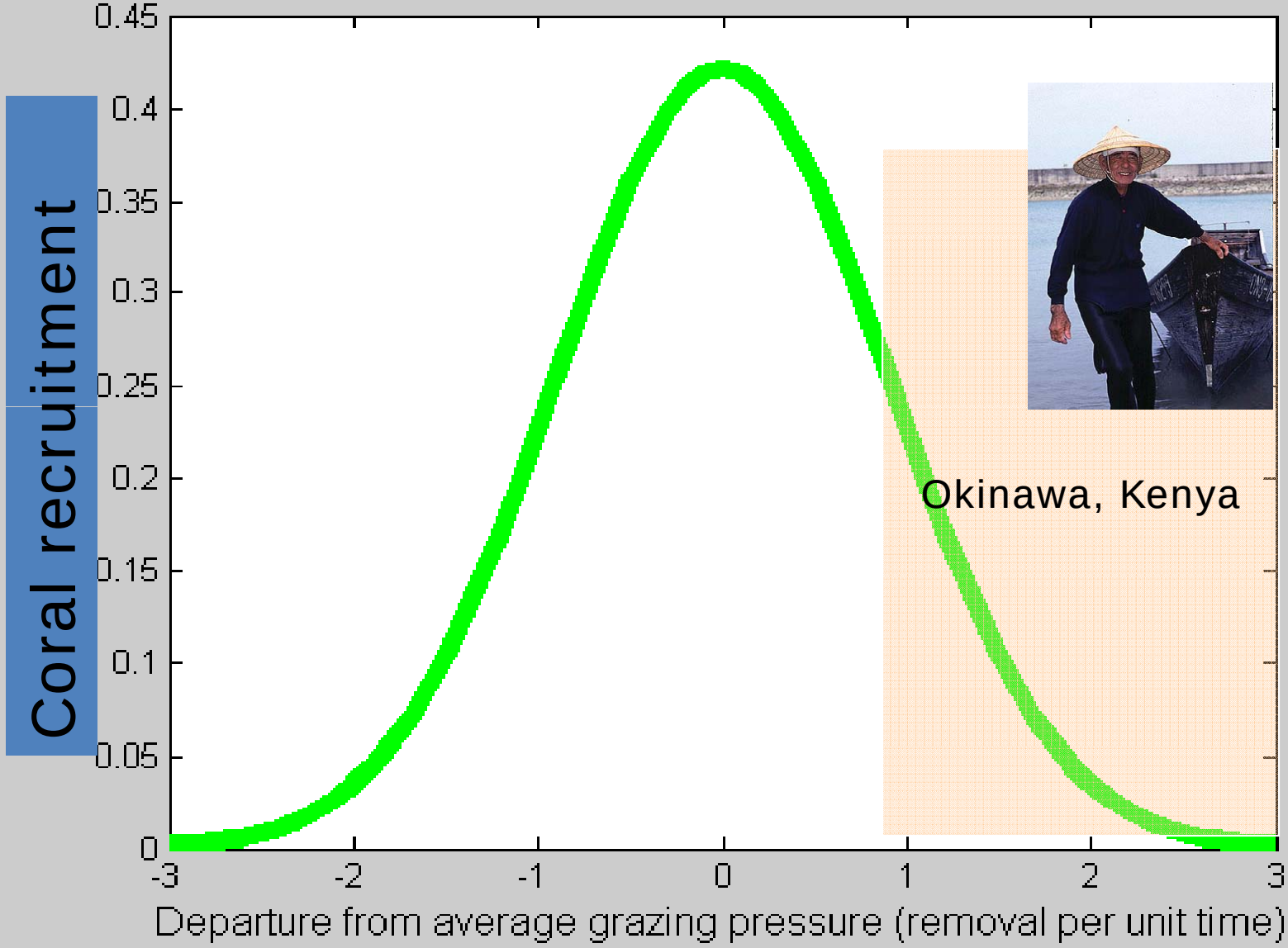
Respiration rate

Context dependent




Herbivory


Coral recruitment
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Caribbean
-3
-2
-1
0
1
2
3
Departure from average grazing pressure (removal per unit time)

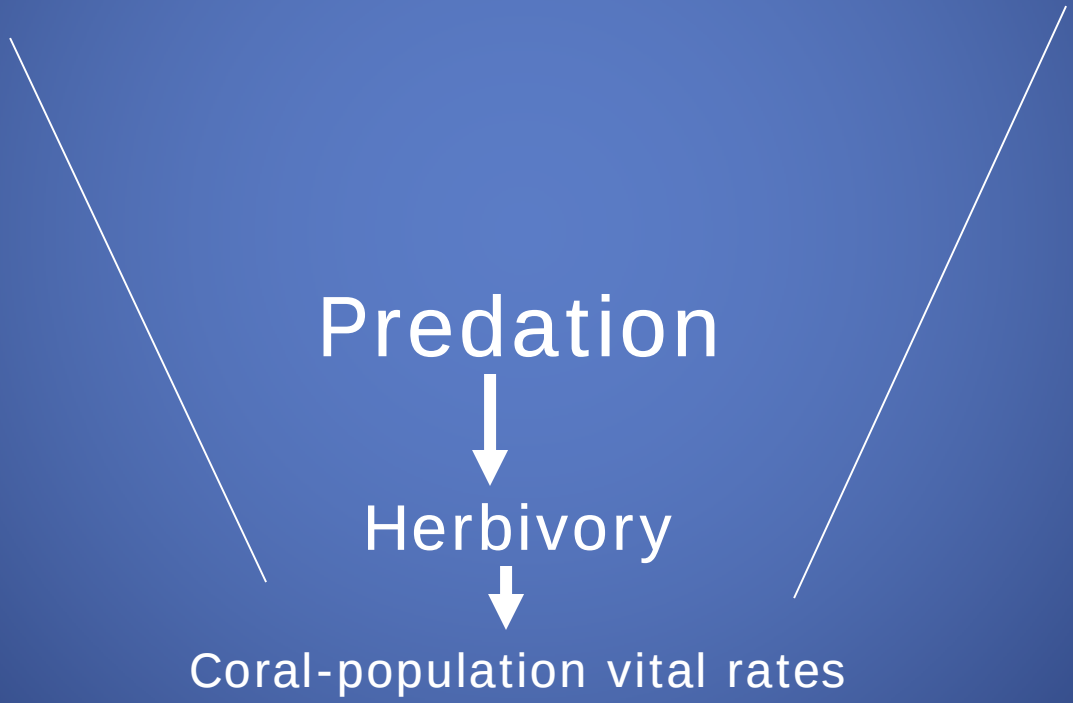

Coral recruitment
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-3
-2
-1
0
1
2
3
Departure from average grazing pressure (removal per unit time)
Okinawa, Kenya

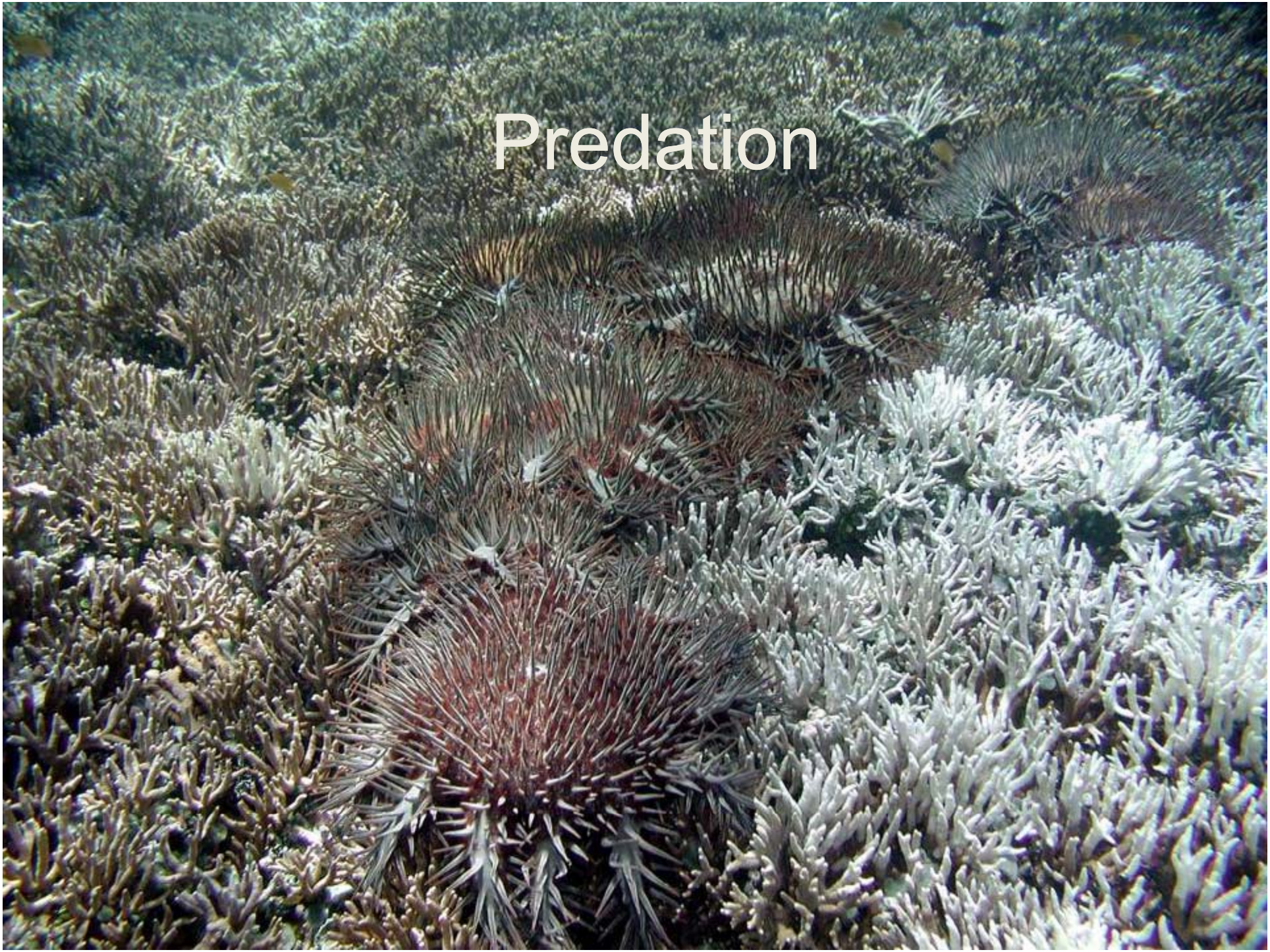
Sesoko Island, Japan

1995

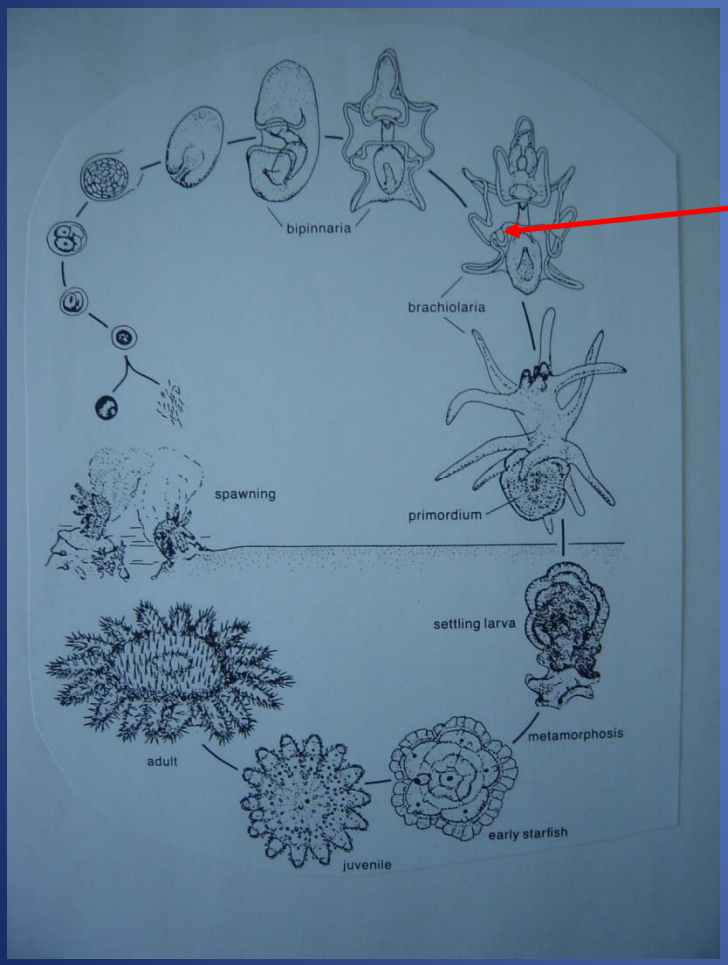
2010

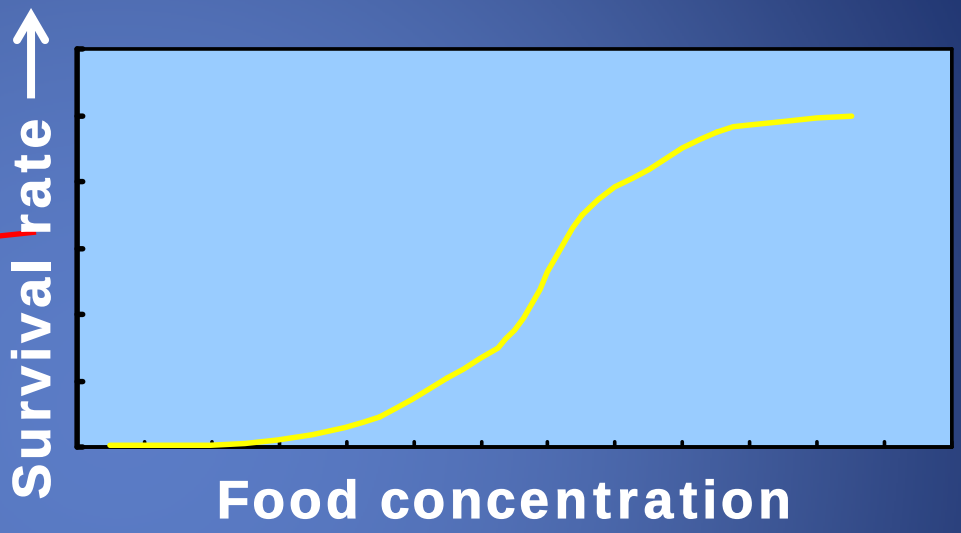
Context dependent

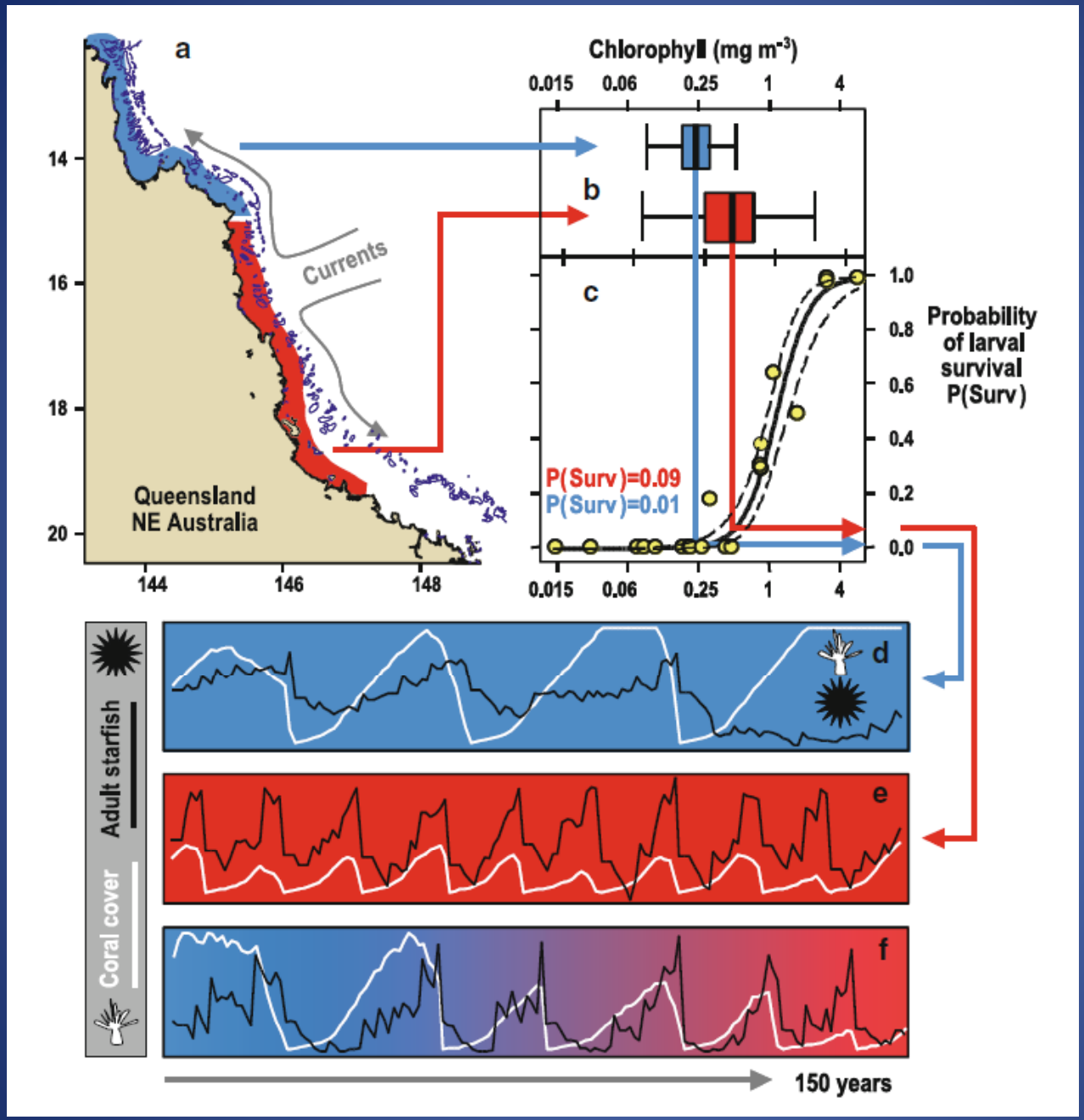



Predation

Birkeland's nutrient limitation hypothesis (1982)

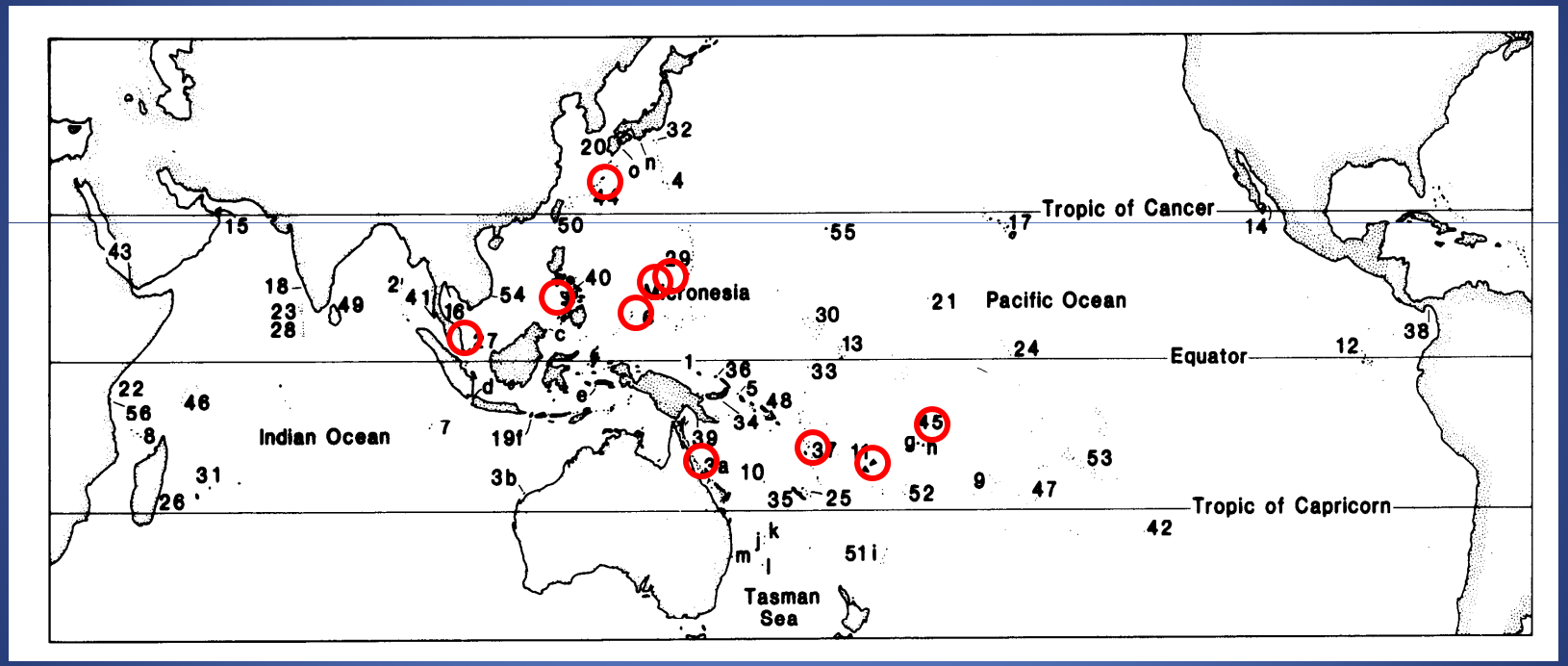


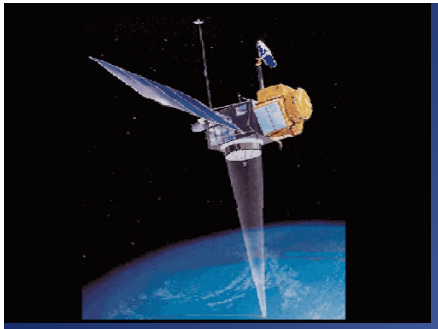




Fabricius et al (2010) Coral Reefs 29: 593-605

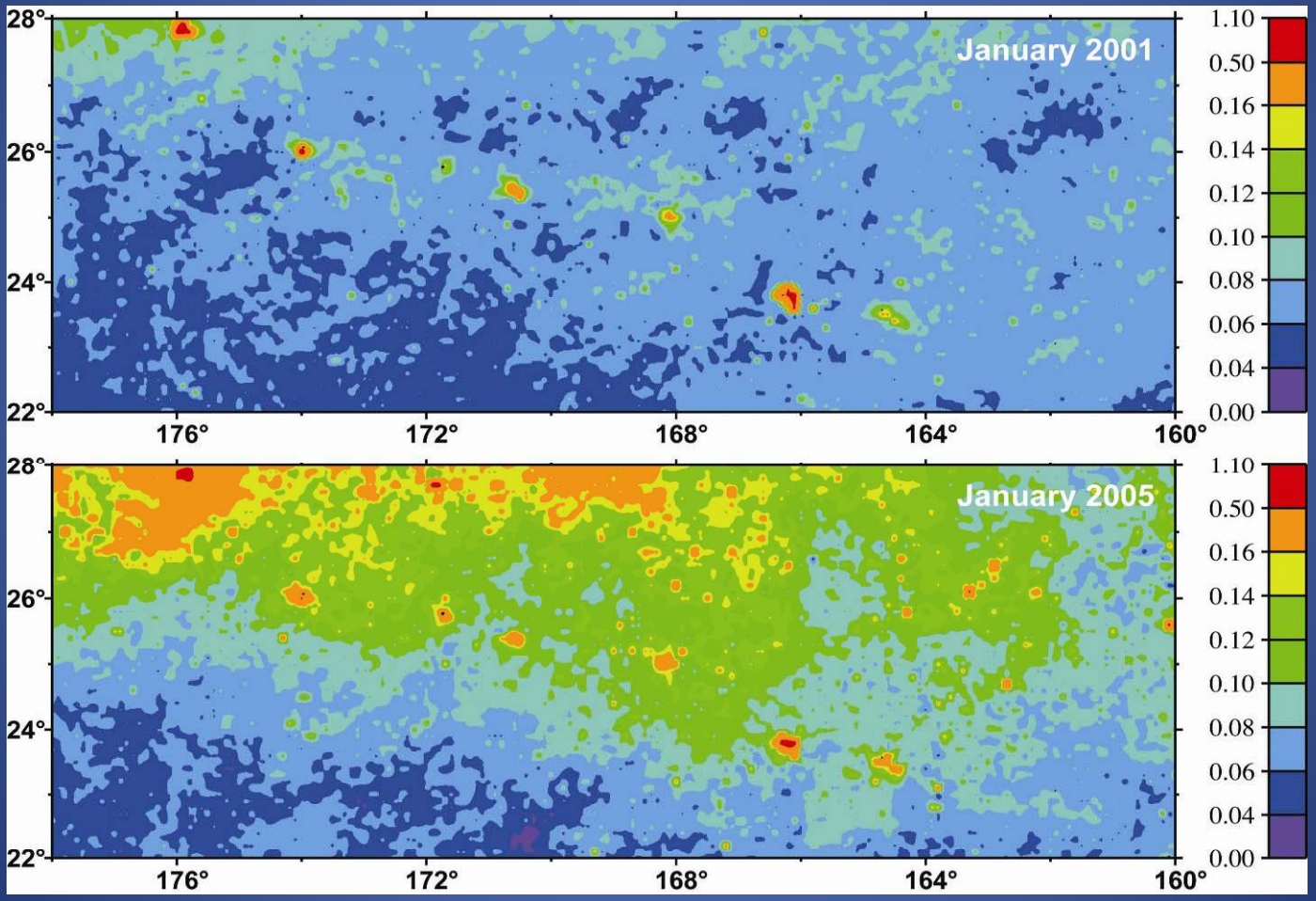
But, how do we get simultaneous outbreaks, where rivers are few, and climatic factors vary?



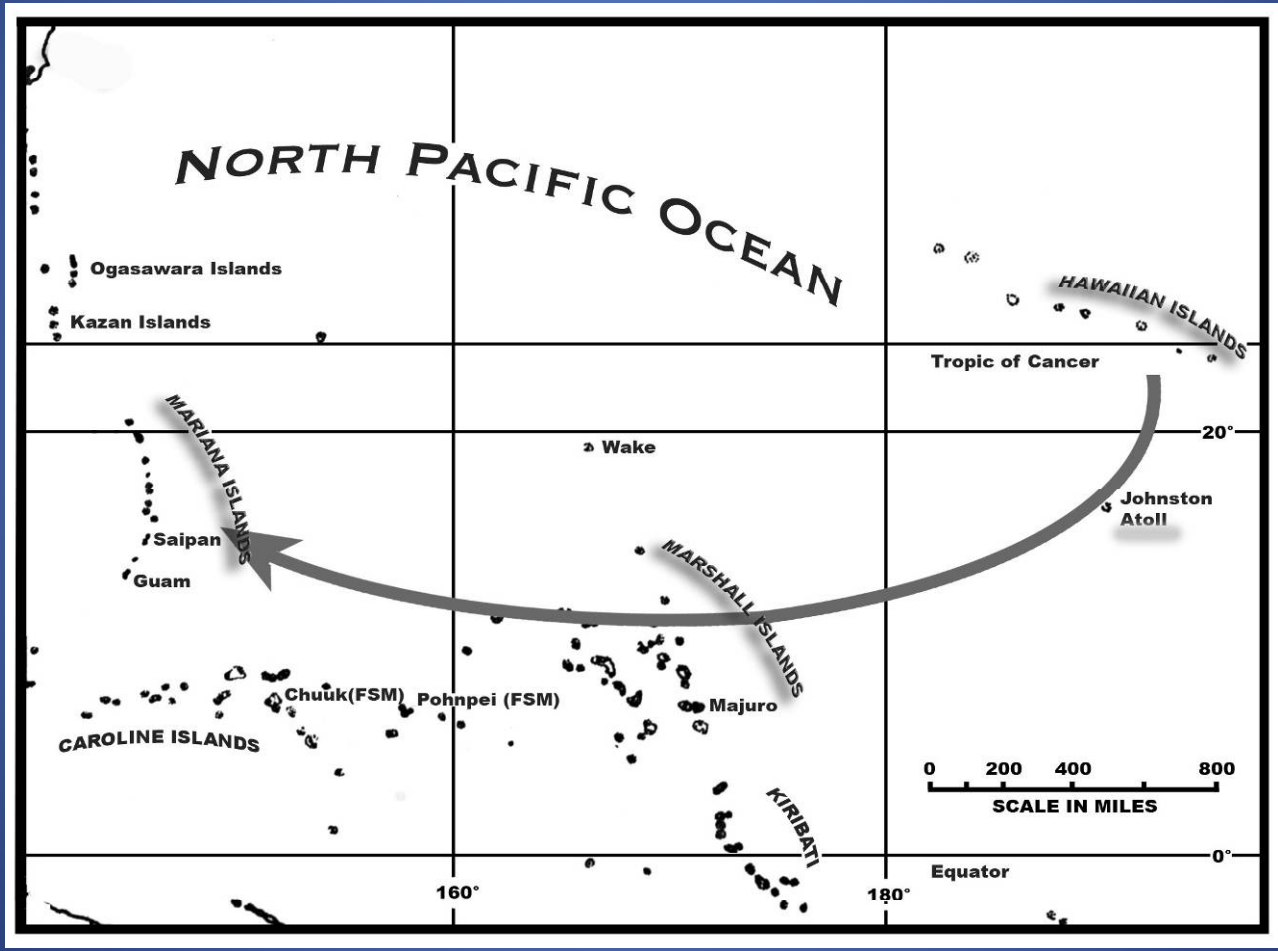


SeaWiFS

Sea-viewing Wide Field-of-view Sensor



Houk P, Bograd S, Van Woesik R (2007) J Oceanography 63: 149-159



Houk P, Bograd S, Van Woesik R (2007) J Oceanography 63: 149-159

- So *Acanthaster* is a problem throughout Micronesia.

- Let’s remove them!

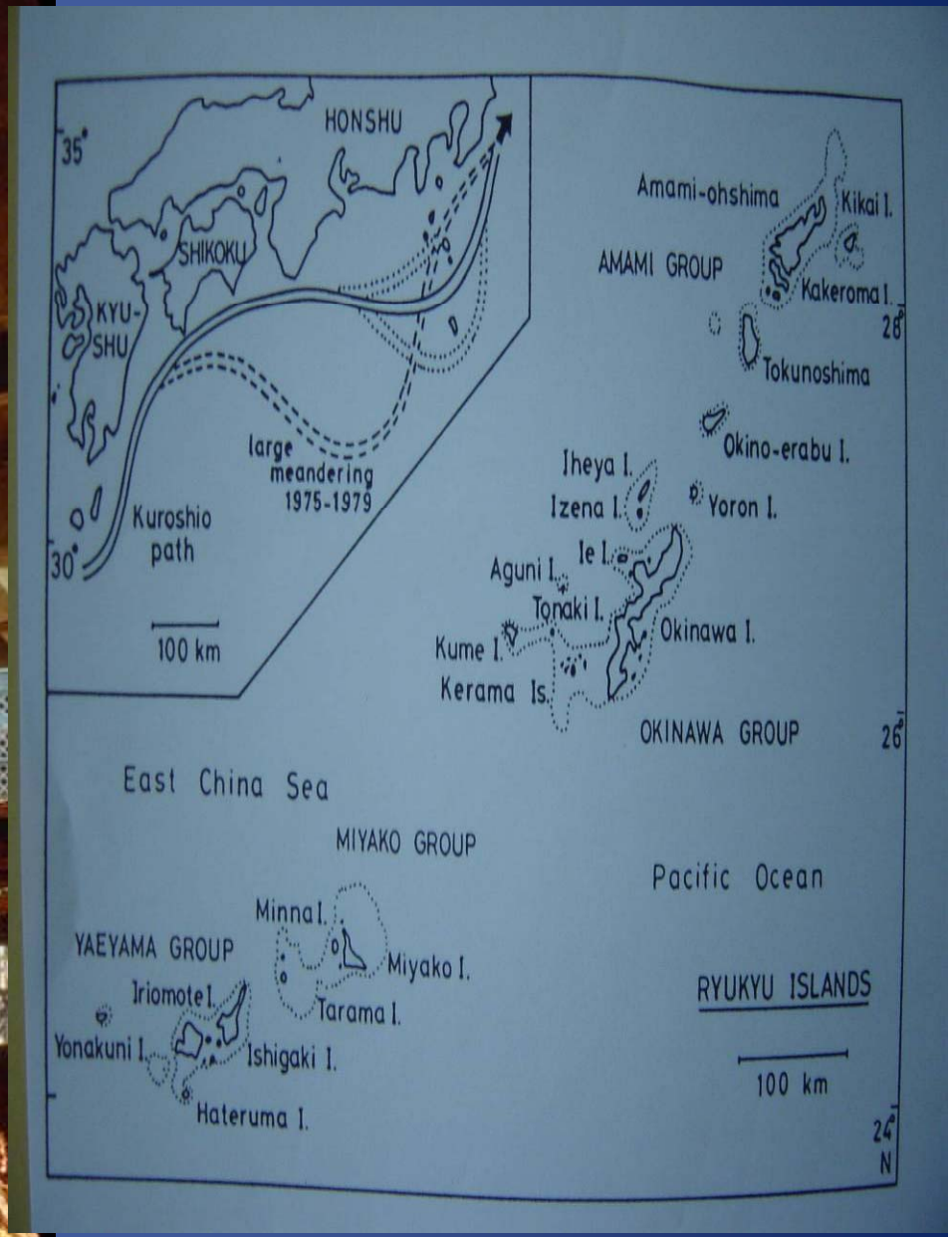
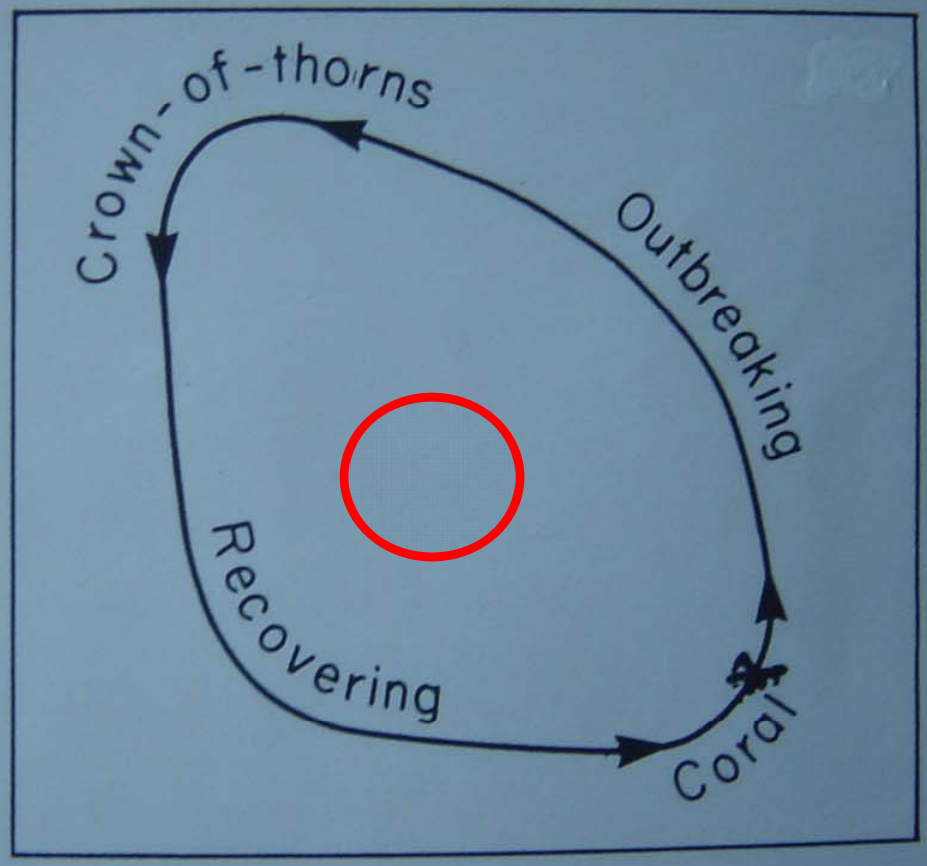

HONSHU
35°
SHIKOKU
KYU-
SHU
large
meandering
1975-1979
Kuroshio
path
30°
100 km
Amami-ohshima
Kikai I.
AMAMI GROUP
Kakeroma I.
28°
Tokunoshima
Okino-erabu I.
Iheya I.
Izena I.
Yoron I.
Ie I.
Aguni I.
Tonaki I.
Okinawa I.
Kume I.
Kerama Is.
OKINAWA GROUP
26°
East China Sea
MIYAKO GROUP
Pacific Ocean
Minna I.
YAEYAMA GROUP
Miyako I.
Iriomote I.
Tarama I.
RYUKYU ISLANDS
Yonakuni I.
Ishigaki I.
100 km
Hateruma I.
24°
N

Table 1. Cost estimates of *Acanthaster* control efforts in Japan. The cost estimates in ( ) indicated those calculated by the bounty of 20 yen per starfish in the years from 1970 to 1975

Locality	Fiscal year	Total number	Total cost (million yen)	Cost per animal (yen)	Total length of coast-line (km)
Miyake I.	1980	3.5×10^3	1.0	290	–
Kushimoto	1973–1979	1.4×10^3	5.7	4200	–
Ashizuri-Uwakai	1973–1983	8.7×10^4	77.5	890	–
Amami I.	1974–1983	8.8×10^5	135.5	160	427
Kikai I.	1979	3.1×10^4	2.9	94	49
Tokuno-shima	1976–1983	8.8×10^4	20.3	230	94
Okino-erabu I.	1982	2.0×10^4	1.9	96	57
Yoron I.	1973–1983	9.9×10^5	66.5	67	25
Izena & Iheya Is.	1973–1979	8.2×10^5	(20)	(24)	51
Okinawa I.	1970–1983	6.1×10^6	(130)	(21)	562
Ie I.	1972–1974	2.0×10^5	(4.0)	(20)	21
Aguni I.	1973	9.2×10^4	(1.8)	(20)	12
Kerama Is.	1972–1981	6.1×10^4	(27)	(440)	110
Tonaki I.	1981	1.1×10^5	3.0	26	26
Kume I.	1972–1973	2.3×10^5	(4.7)	(20)	53
Miyako Is.	1979–1983	1.5×10^6	39.2	26	187
Yaeyama Is.	1972–1983	1.6×10^6	93.1	60	336
Total		1.3×10^7	630	50	

Removing *Acanthaster*, terminates the boom and bust cycles – and generates a *chronic* problem.



Real solution

Control terrestrial discharge on coral reefs (from rivers and local sources).

Context dependent

Oceanography

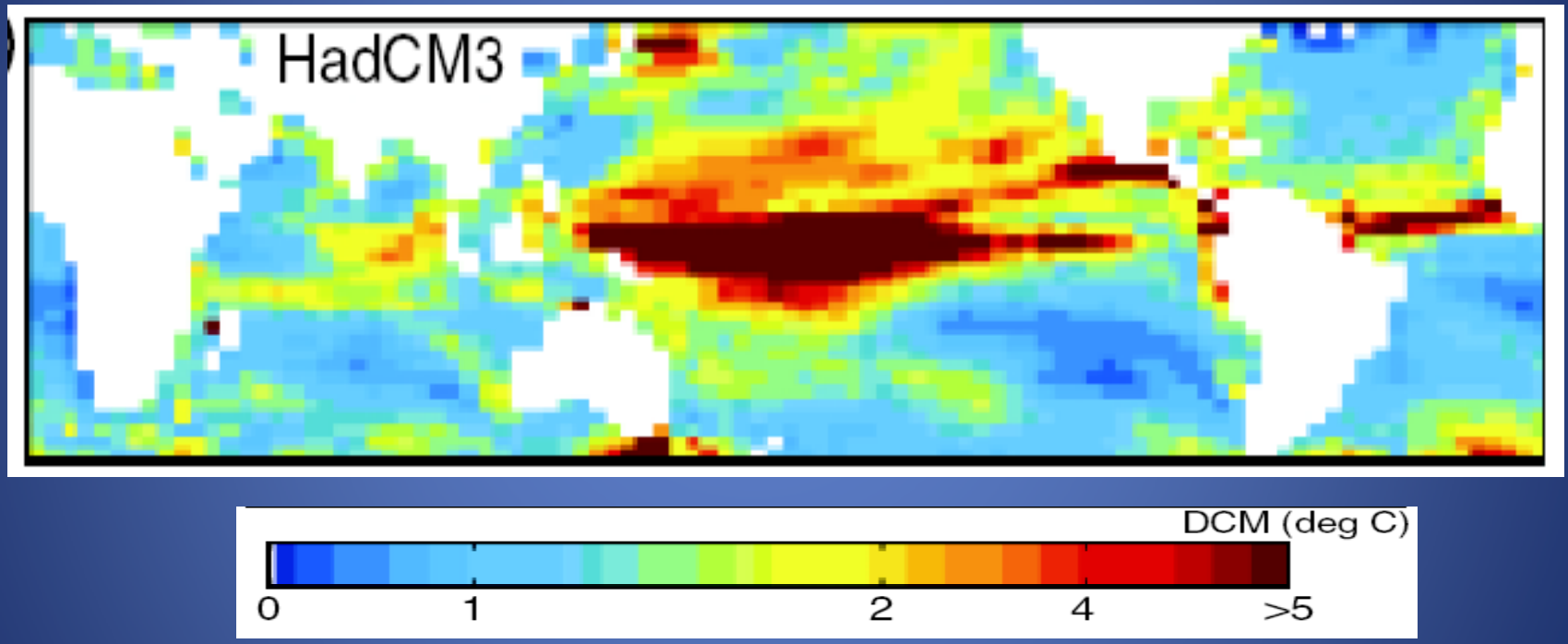
Predation

Herbivory

Coral-population vital rates

Seawater temperature changes (models)

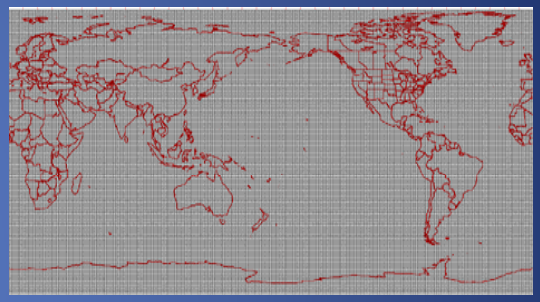
2030-2039



Donner et al (2005) Global Change Biol 11: 2251-2265

Massive corals: historical archives of shallow-water tropical ecosystems

Massive corals: historical archives of shallow-water tropical ecosystems



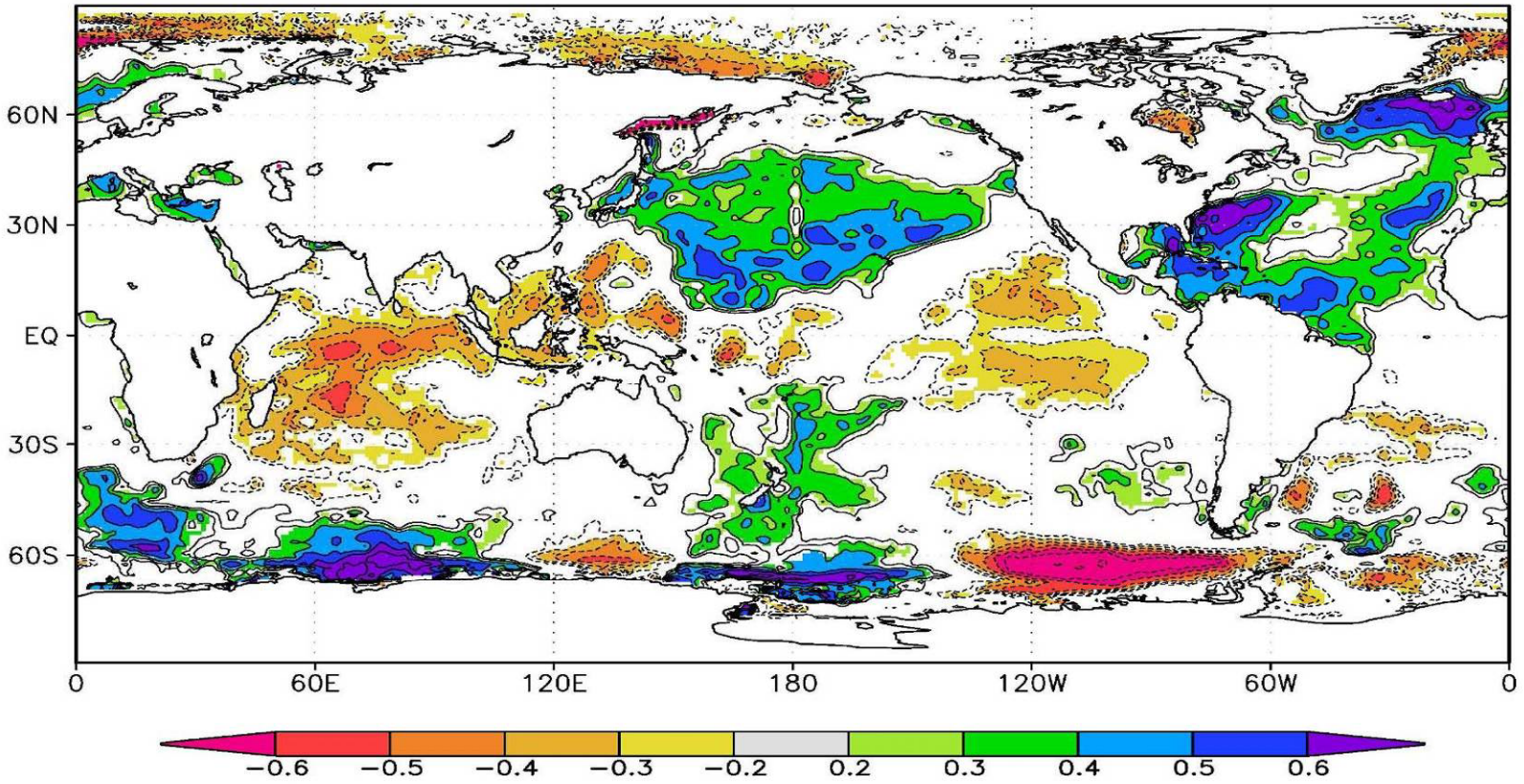
SST (source: HadISST1.1)

1°x 1°(1870-2006)

$\delta^{18}O$ data, from 1519 to 2000

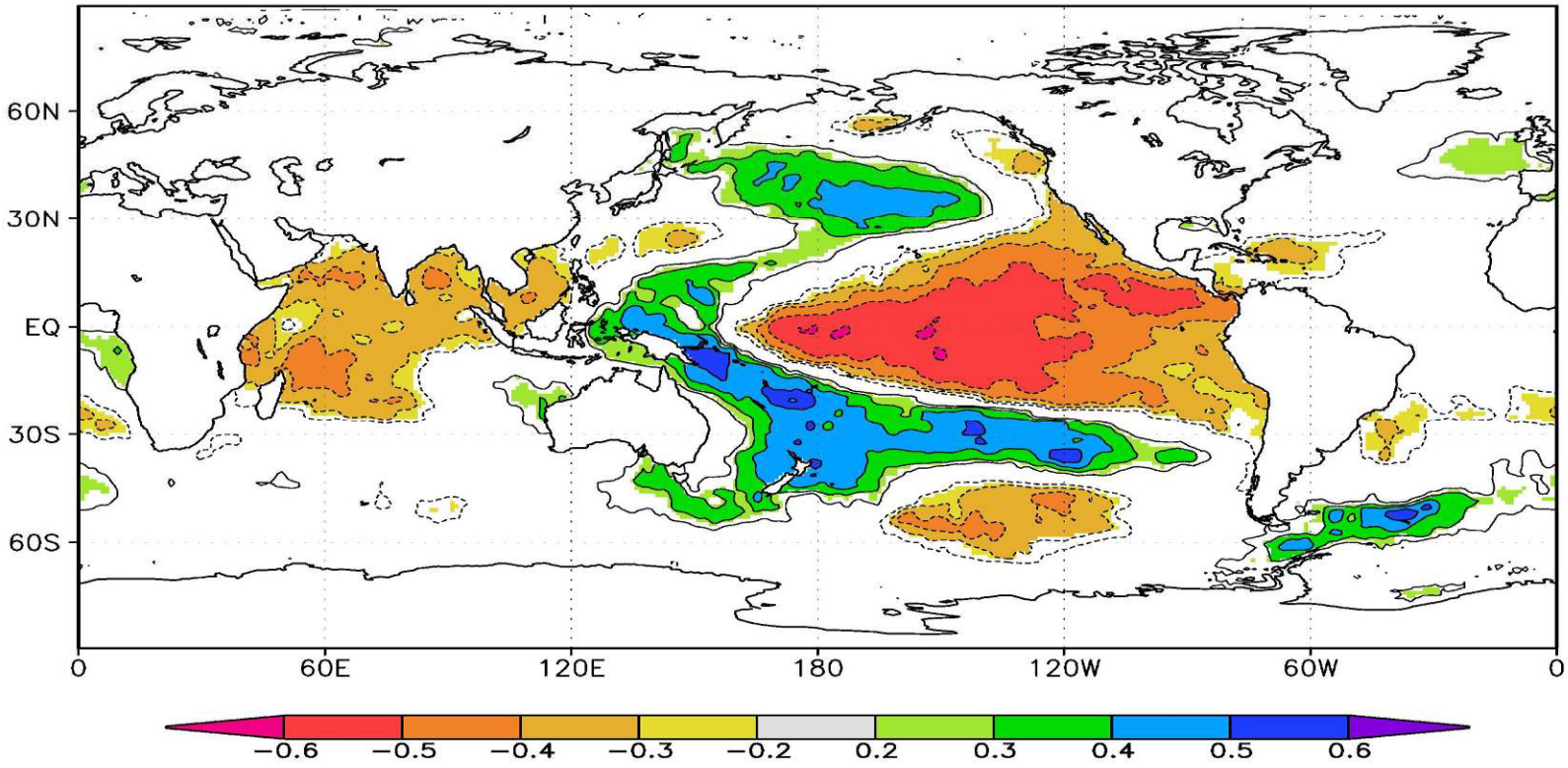
32ºN to 28ºS and 173ºE to 162ºW

low-frequency mode (> 54 year component)

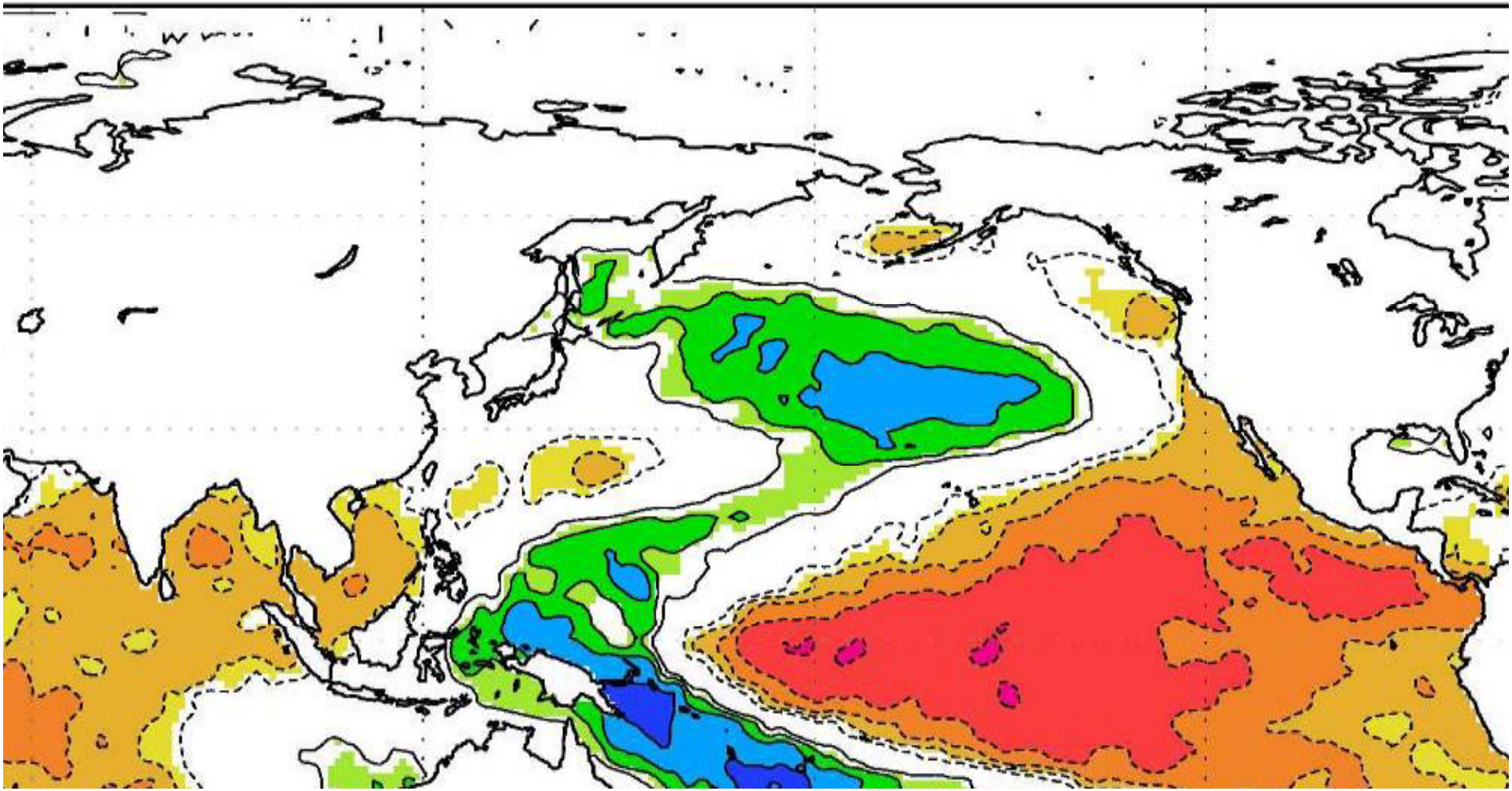


Thompson & van Woesik (2009) Proc Royal Soc 276: 2893-2901

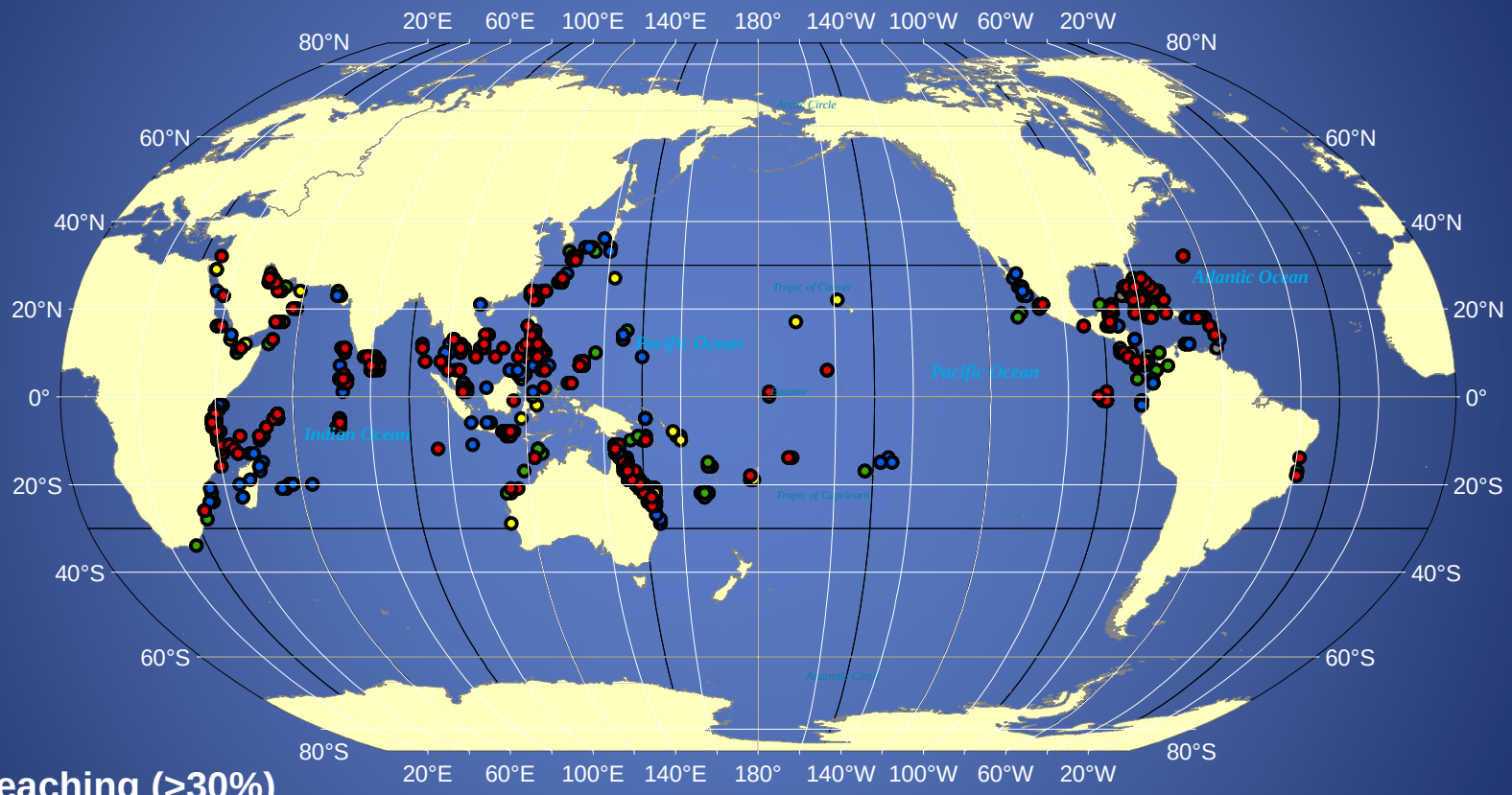
High-frequency mode (5.7 years)



Thompson & van Woesik (2009) Proc Royal Soc 276: 2893-2901

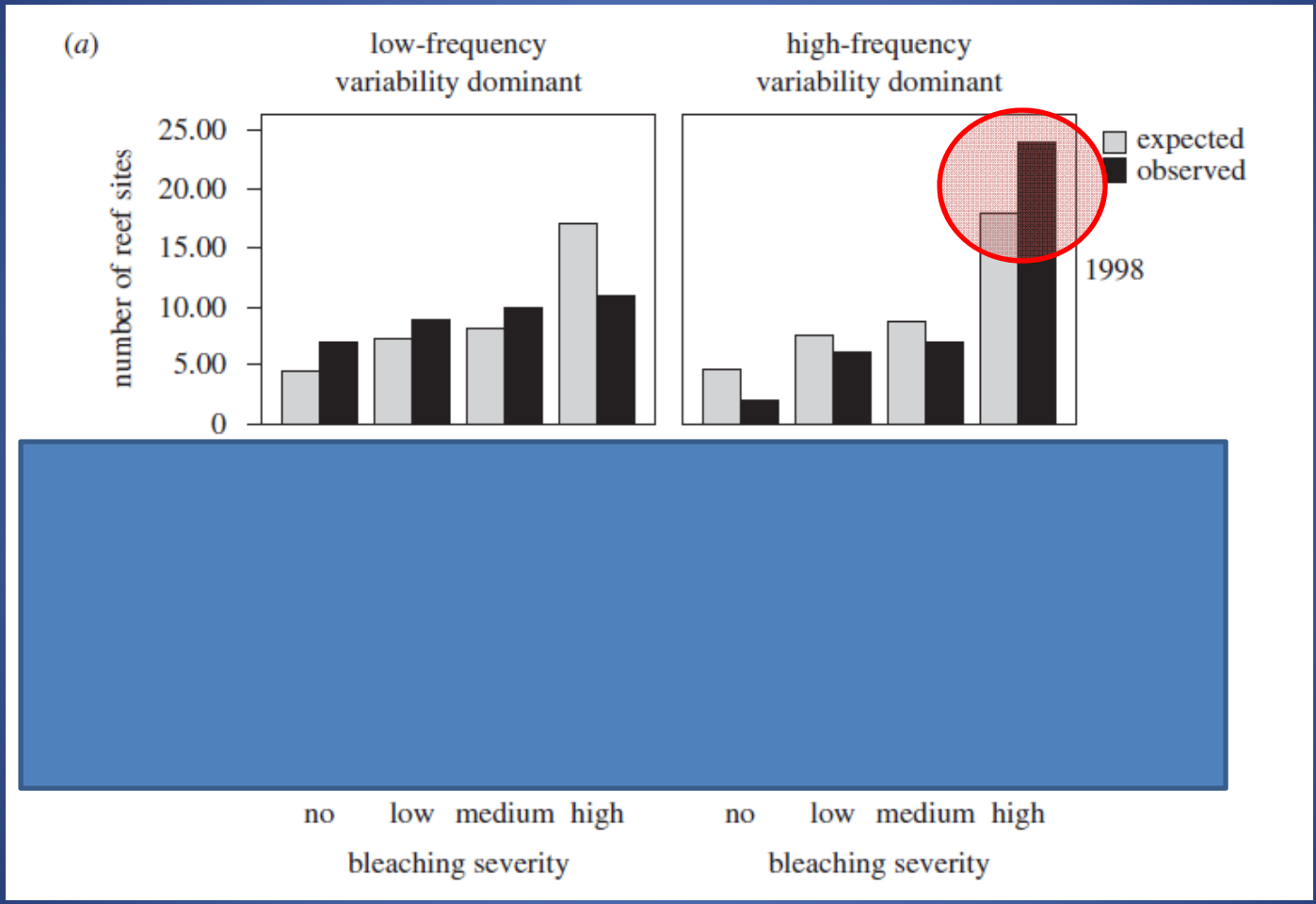


ReefBase Bleaching Records

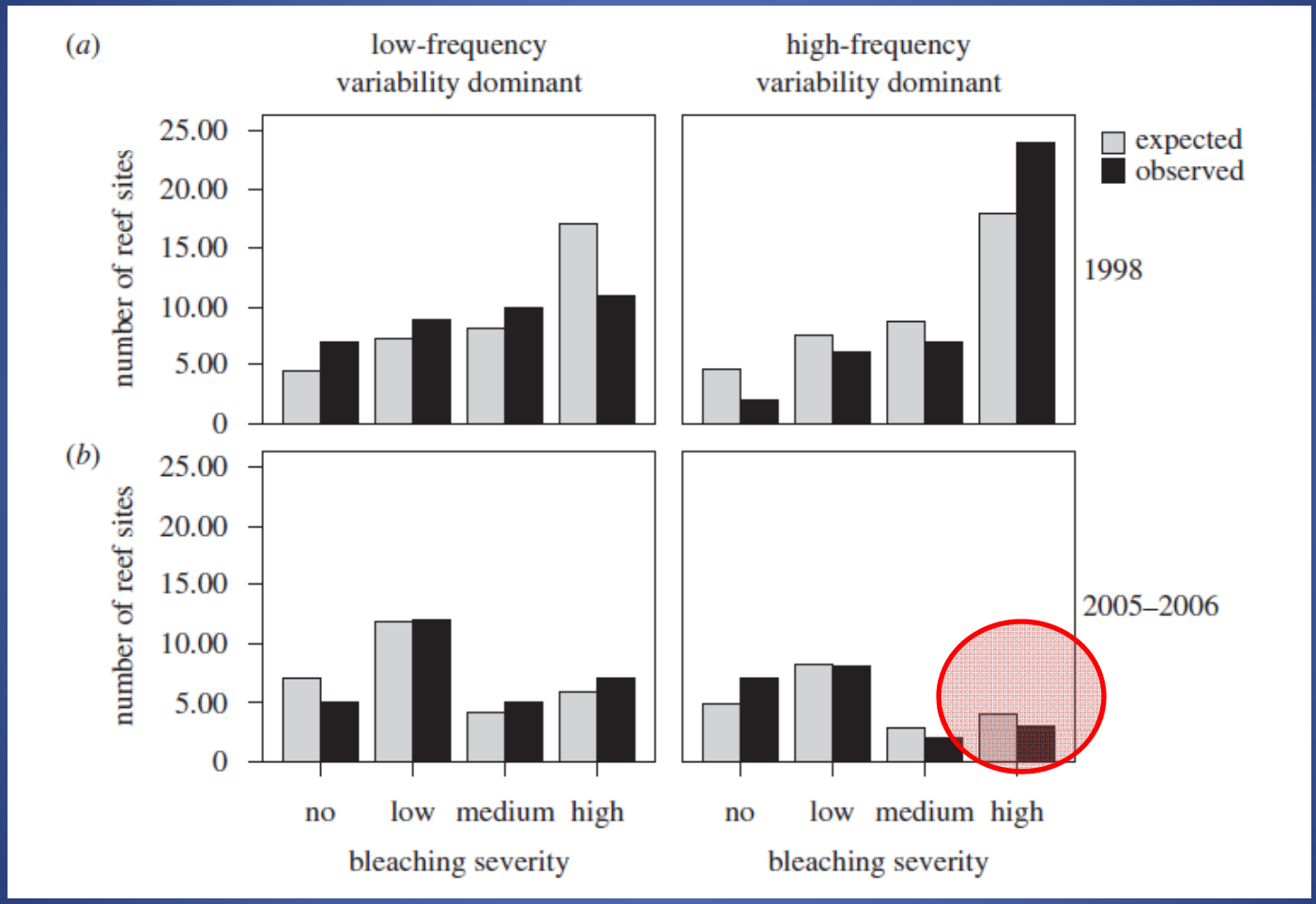


- High Bleaching (>30%)
- Medium Bleaching (10-30%)
- Low Bleaching (1-10%)
- No Bleaching (0%)
- Bleaching Severity Unknown

n= 2132



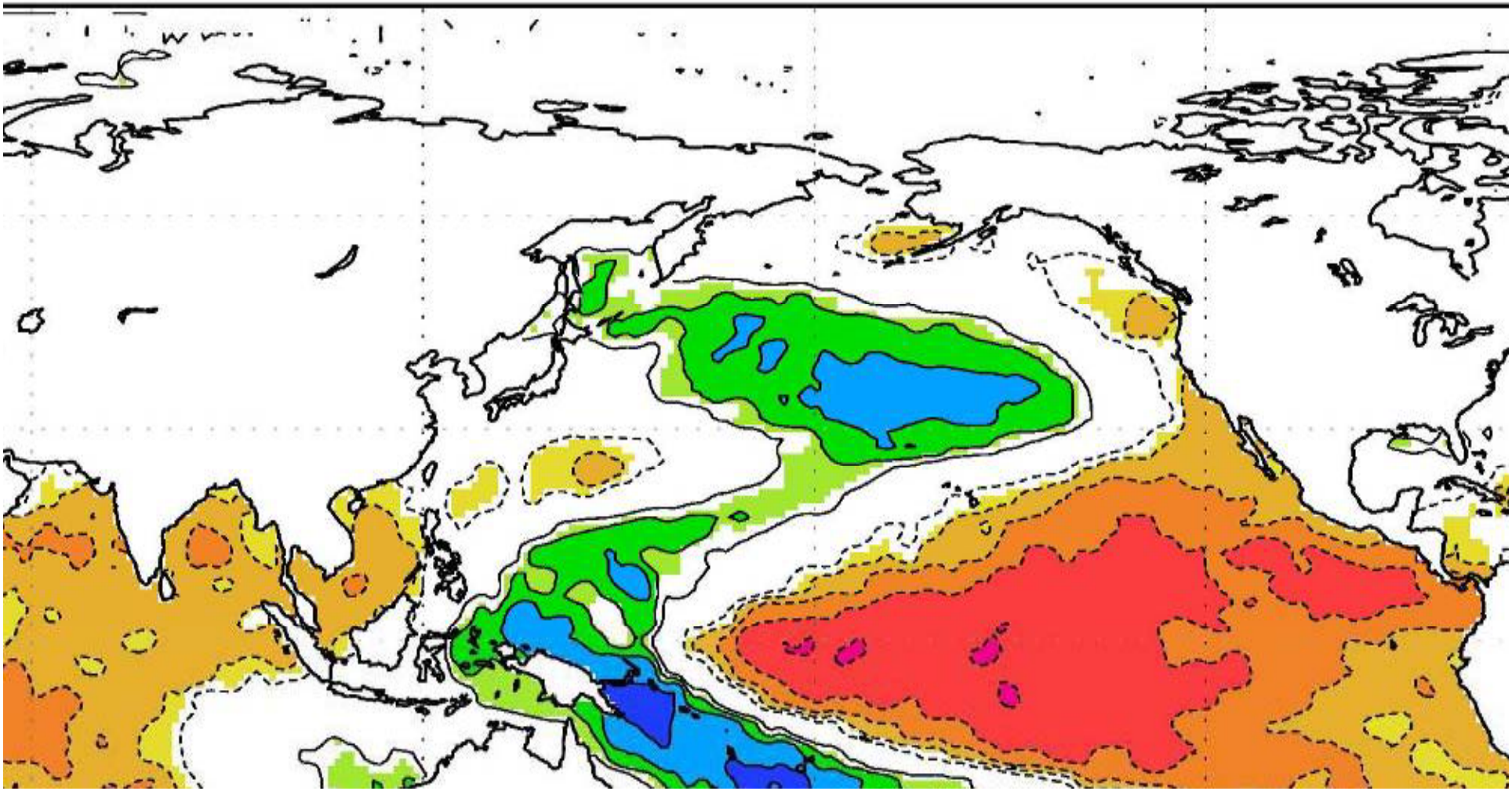
Thompson & van Woesik (2009) Proc Royal Soc 276: 2893-2901

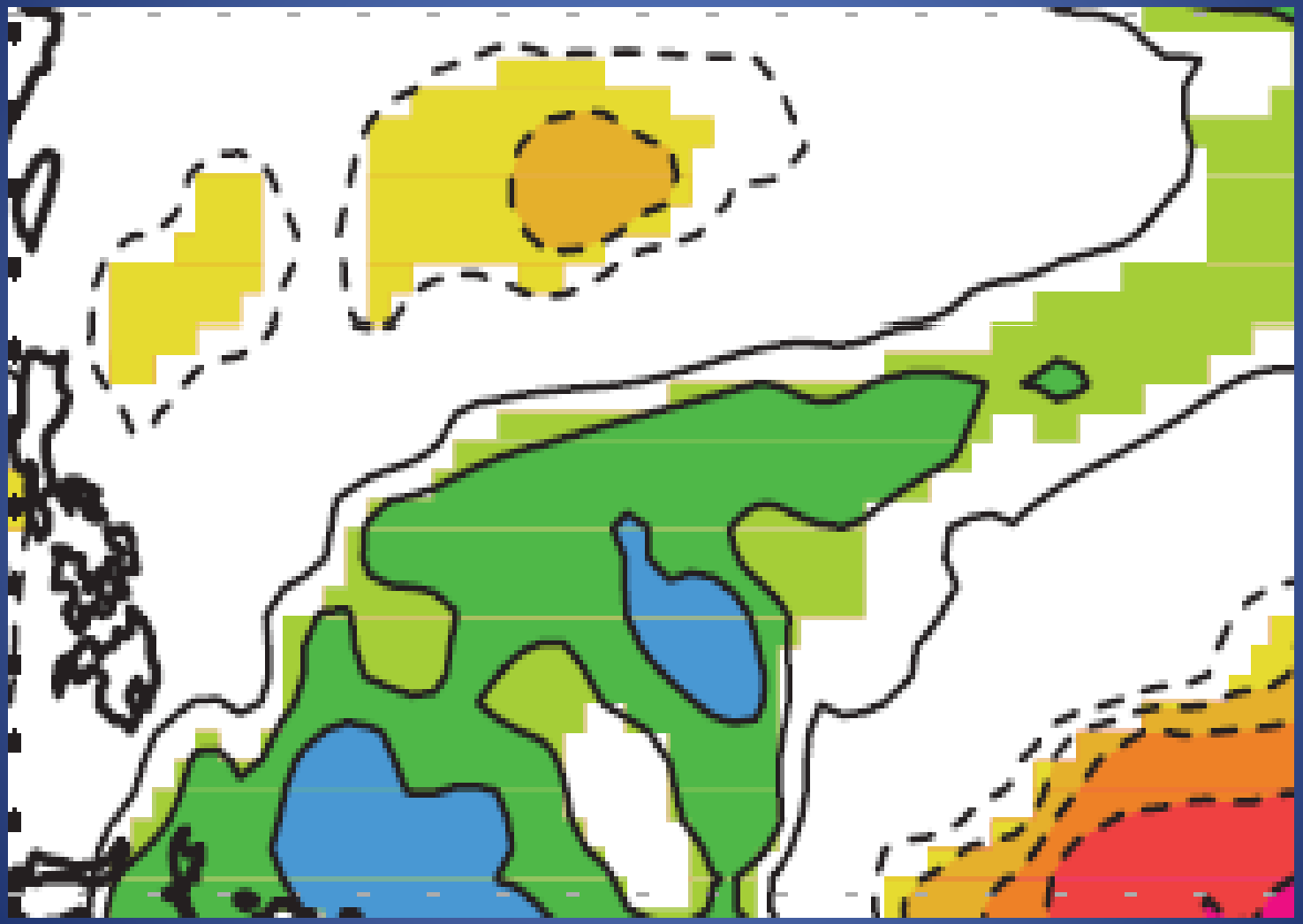


Thompson & van Woesik (2009) Proc Royal Soc 276: 2893-2901

Corals at sites with historically high-frequency temperature anomalies will be less likely to bleach during contemporary thermal stress events.

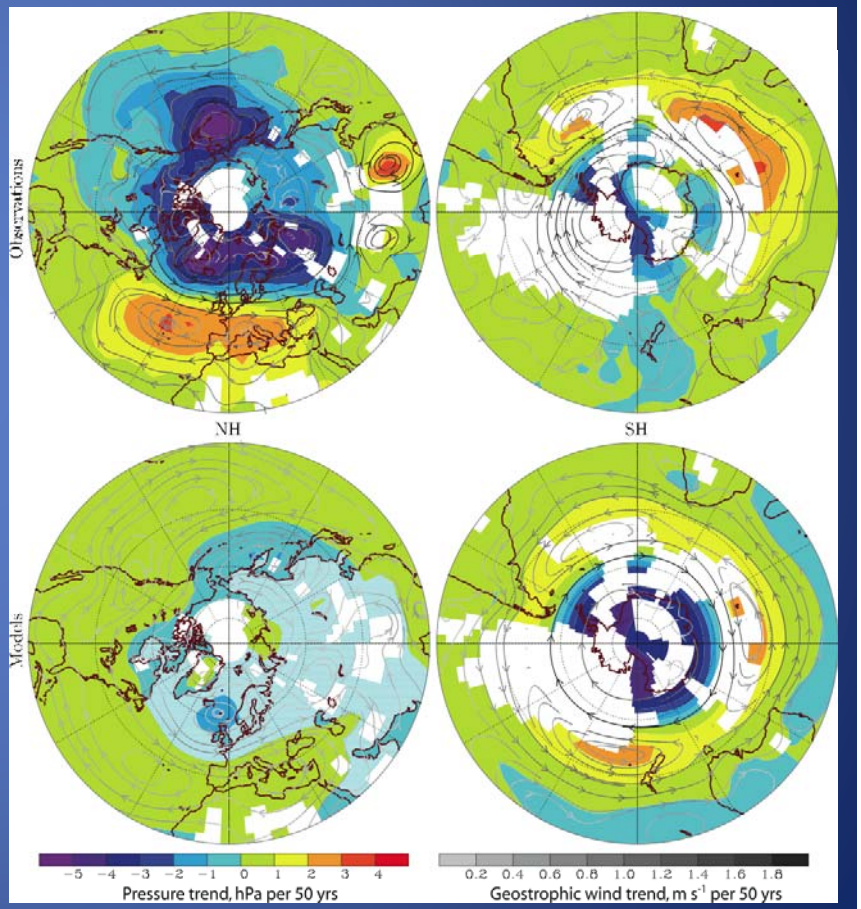
Thompson & van Woesik (2009) Proc Royal Soc 276: 2893-2901





Winds of change

… a weakening of the Asian summer monsoon circulations as the temperature contrast between the continent and ocean decreases.



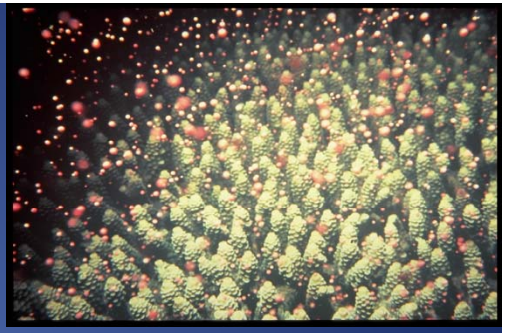
Winds of change

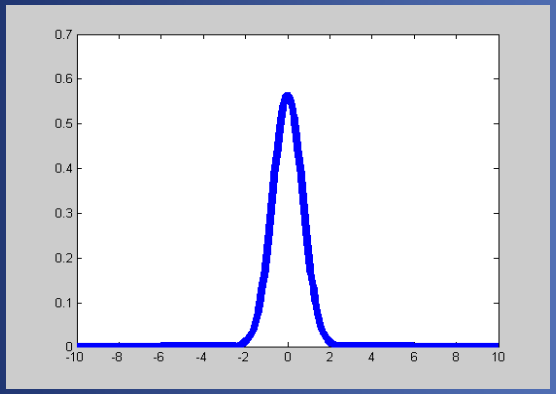
…wind speeds across the USA have decreased by an average of .5 percent to 1 percent per year since 1973

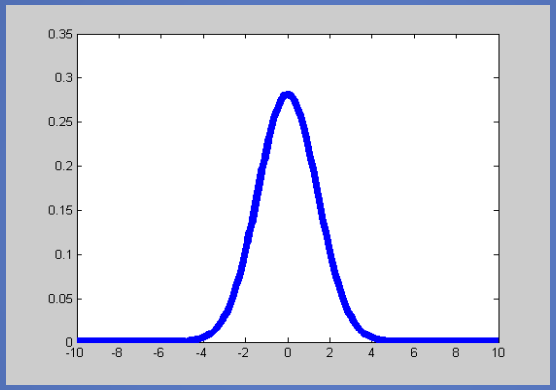
Pryor (2008) Journal of Geophysical Research – Atmospheres 113

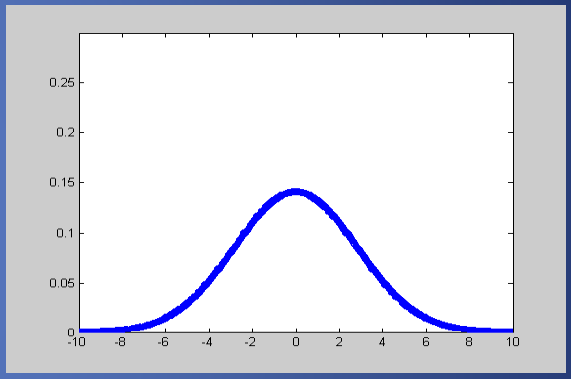
doi:10.1029/2008JD010251.

Climate change and coral spawning





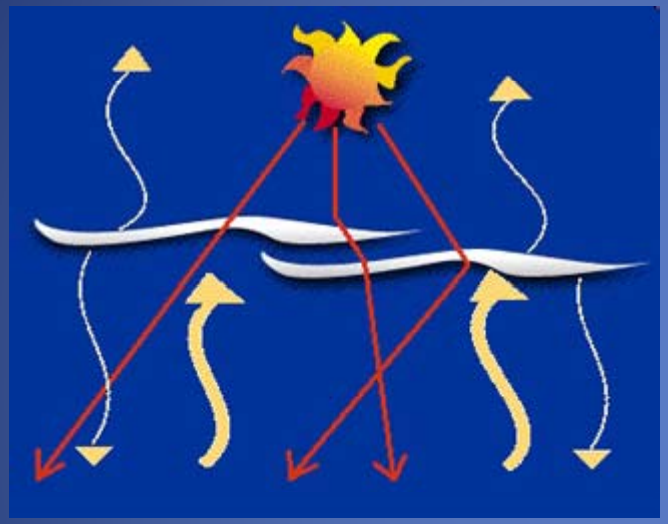


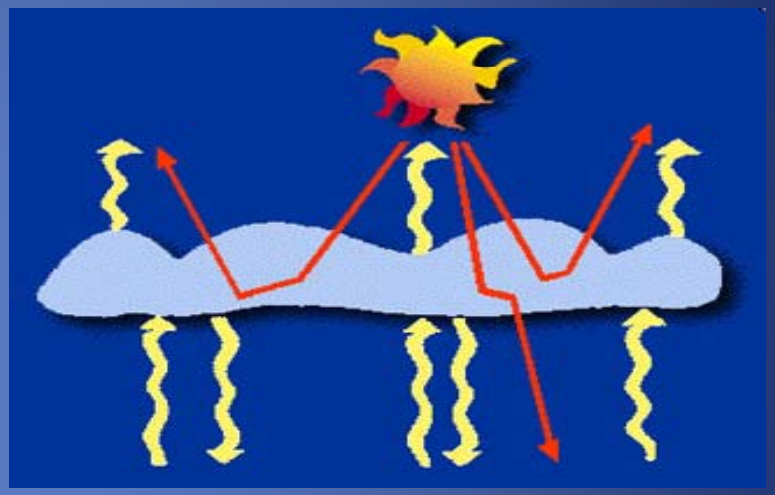


Selective pressure

Away from synchronization

How will cloud cover change?



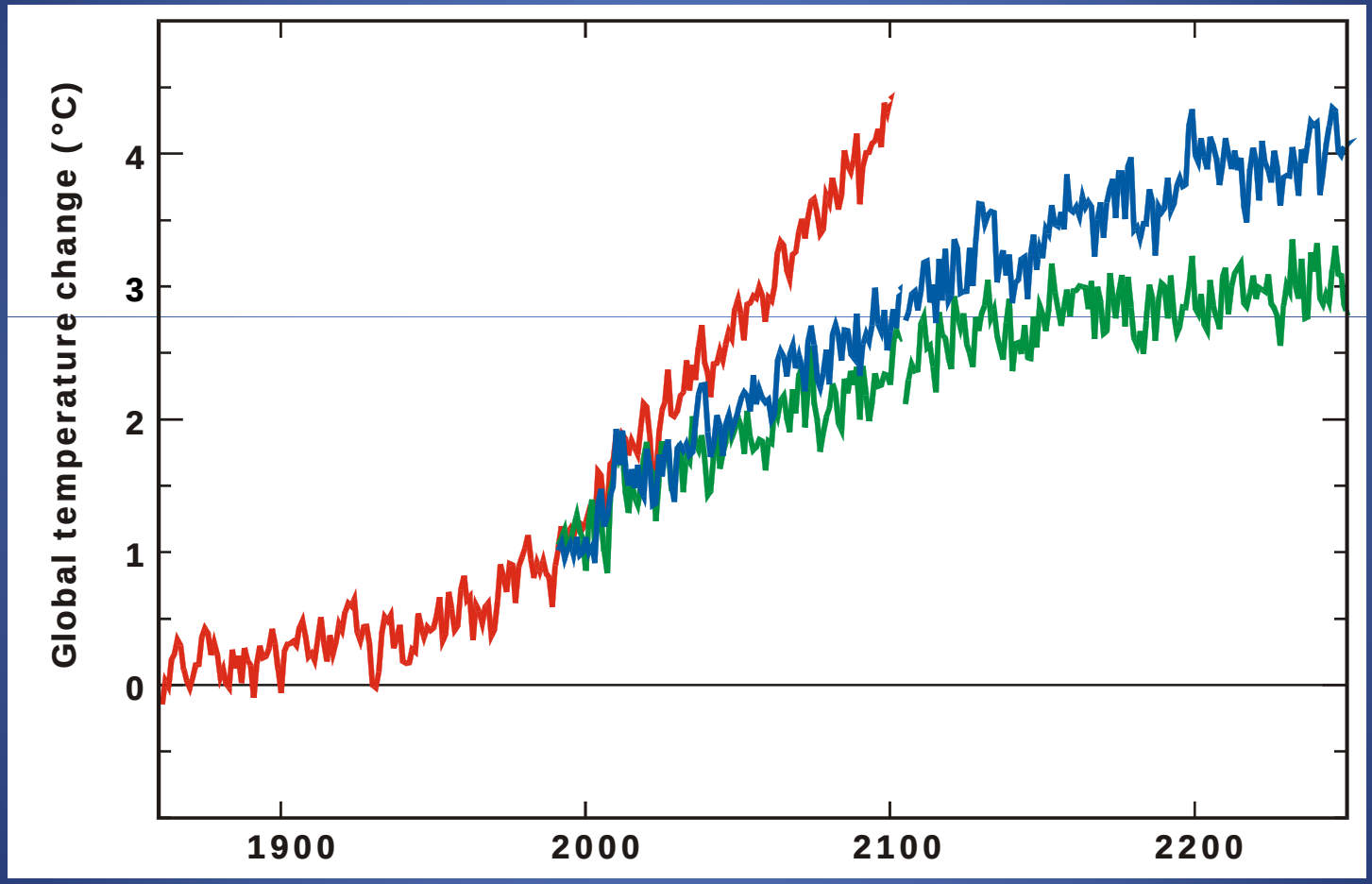


- Recent study, fewer low, dense clouds formed over a region in the Pacific Ocean when temperatures warmed.

Lau & Wu 2003. Geophysical Res letters 30: 2290

More bleaching?

The degree to which global warming changes life on Earth depends on our decisions



Source: Hadley Centre for Climate Prediction and Research

What can we do here, now?

What can we do here, now?

1. We need a comprehensive monitoring program for Micronesia.

- **Immediate Action Item:**

  Generate Micronesian Fellowship program … (intern positions, undergraduate & graduate fellowships), short courses are not enough… need a long-term commitment.

What can we do here, now?

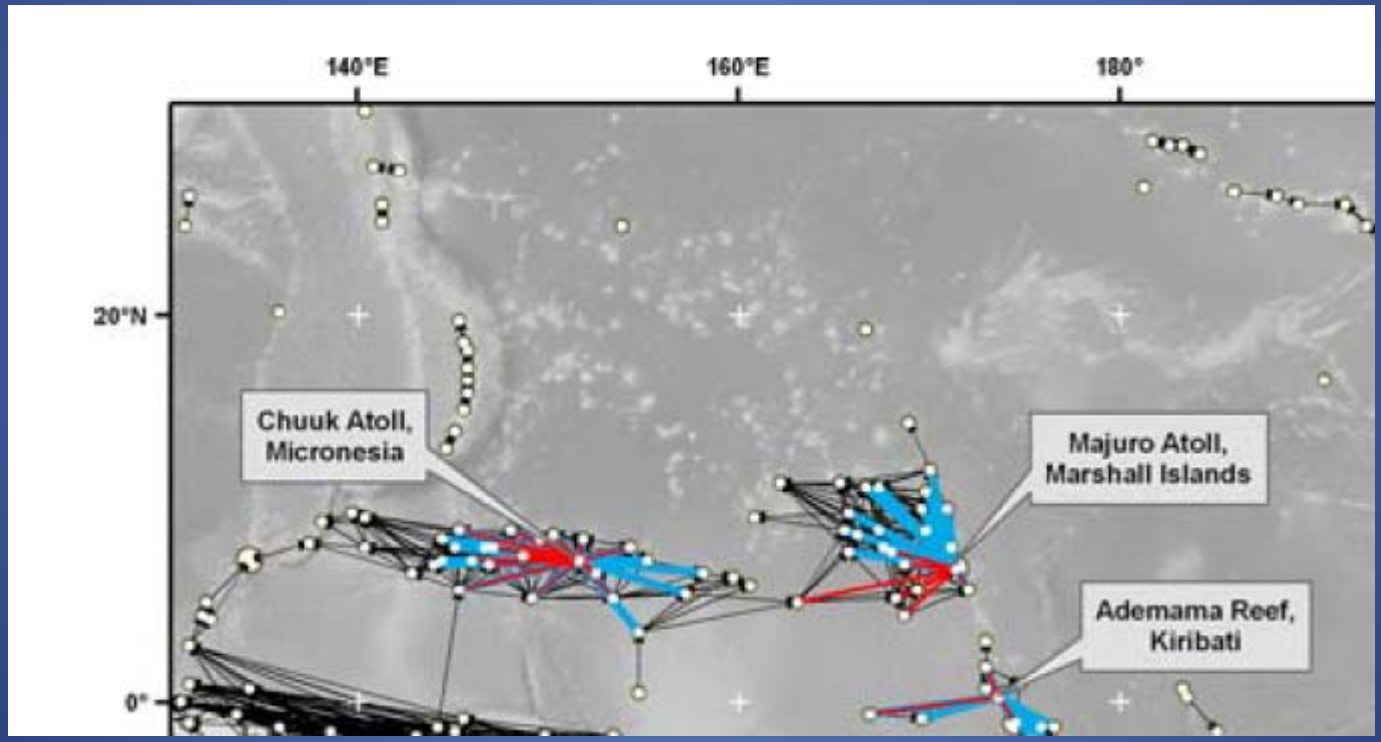
1. **We need a comprehensive monitoring program for Micronesia.**

2. **Establish and strictly enforce *networks* of Marine Protected Areas that include No-Take Areas.**

- Local connectivity suggests that *local protection and management* will lead to local benefits.

- Local action and protection also buys time for adaptation.

Most recruitment by corals and fishes is local (1-10 km), but enough larvae are widely dispersed to ensure effective panmictic populations (100s km)



Treml et al (2008) Landscape Ecol 23: 19-36

What can we do here, now?

1. **We need a comprehensive monitoring program for Micronesia.**

2. **Establish and strictly enforce *networks* of Marine Protected Areas that include No-Take Areas.**

3. **Control terrestrial discharge on coral reefs (from rivers and local sources).**

What can we do here, now?

1. **We need a comprehensive monitoring program for Micronesia.**

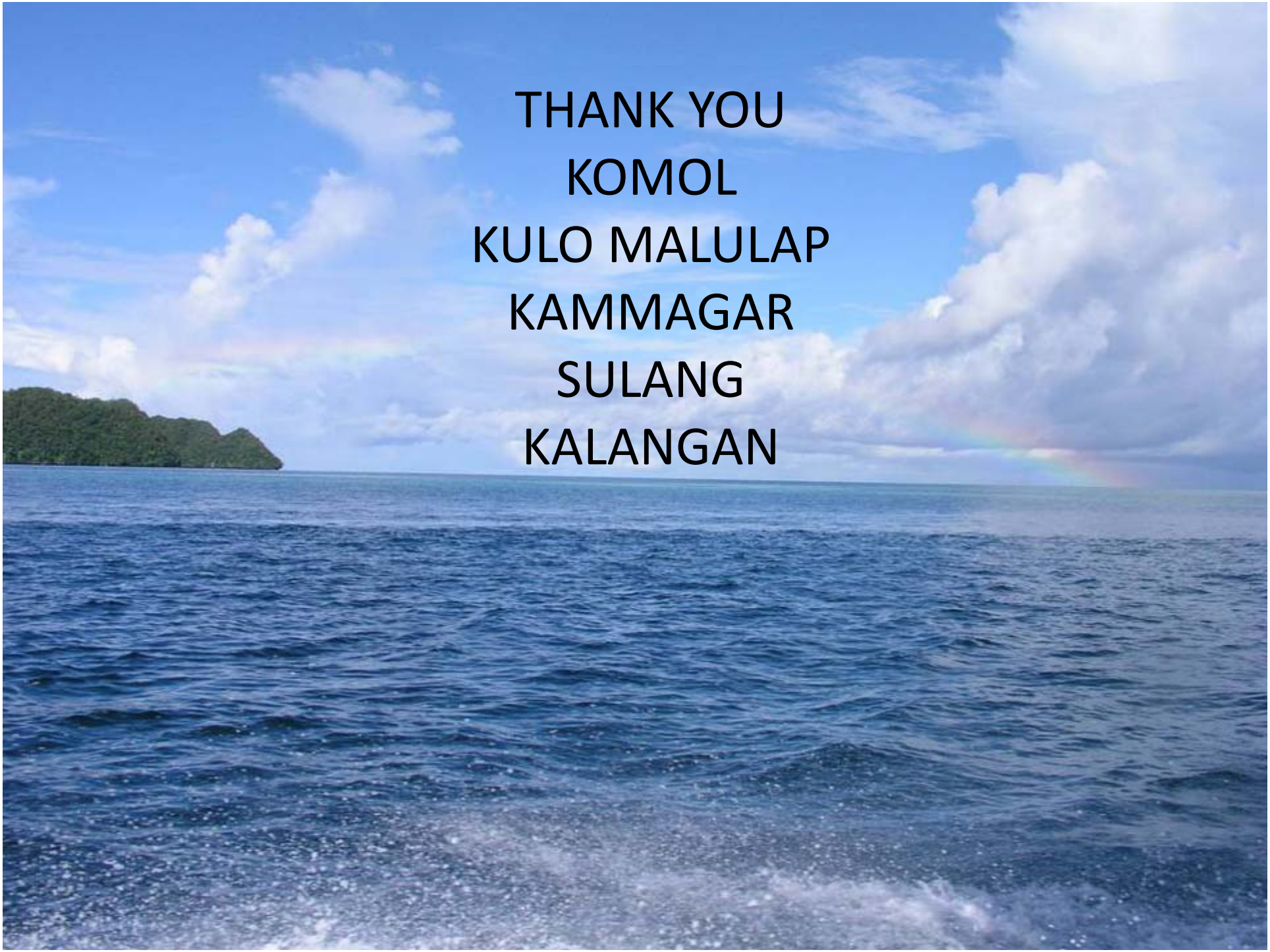
2. **Establish and strictly enforce *networks* of Marine Protected Areas that include No-Take Areas.**

3. **Control terrestrial discharge on coral reefs (from rivers and local sources).**

4. **Need regional and global action to reduce effects of climate change.**

Conclusions

- Projected changes in climate is set to drive temperature and seawater chemistry to levels outside the envelope of modern reef experience.
- Some reef organisms will adapt to climate change more than others – some will be winners, while others will be losers.
- Local connectivity suggests that local protection and management will lead to local benefits. Action and protection also buys time for adaptation.


THANK YOU
KOMOL
KULO MALULAP
KAMMAGAR
SULANG
KALANGAN