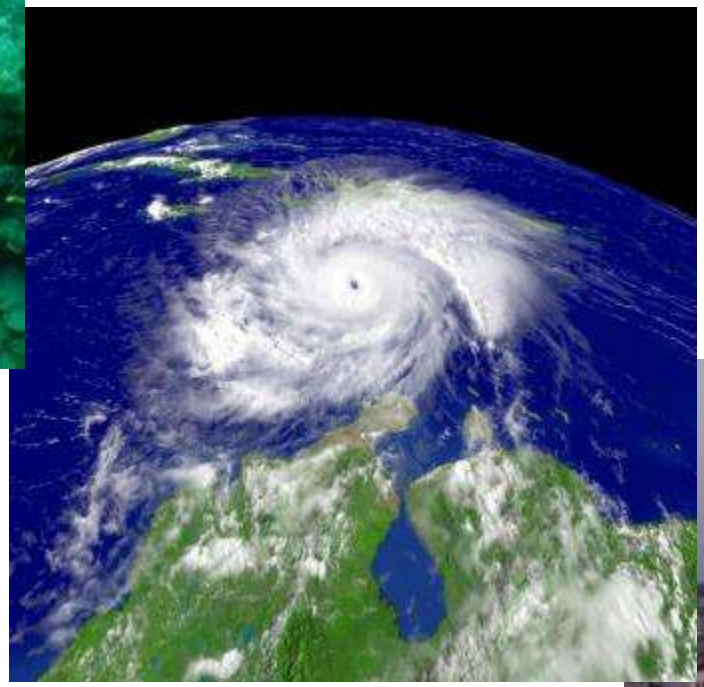
How fragile is our planet?
Impact of climate change on coral reefs and the people who depend on them



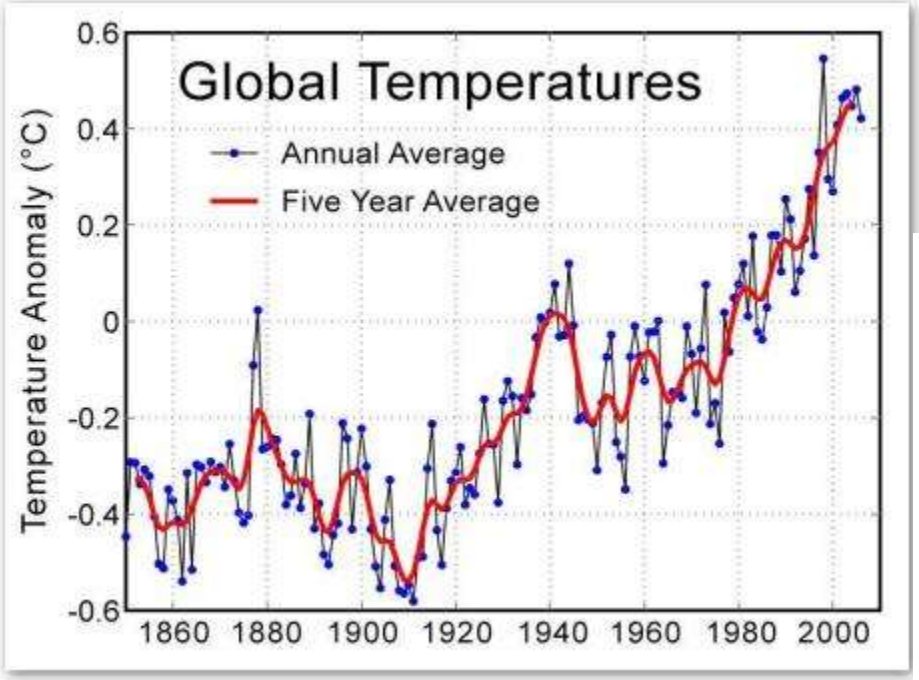
University of Bedfordshire

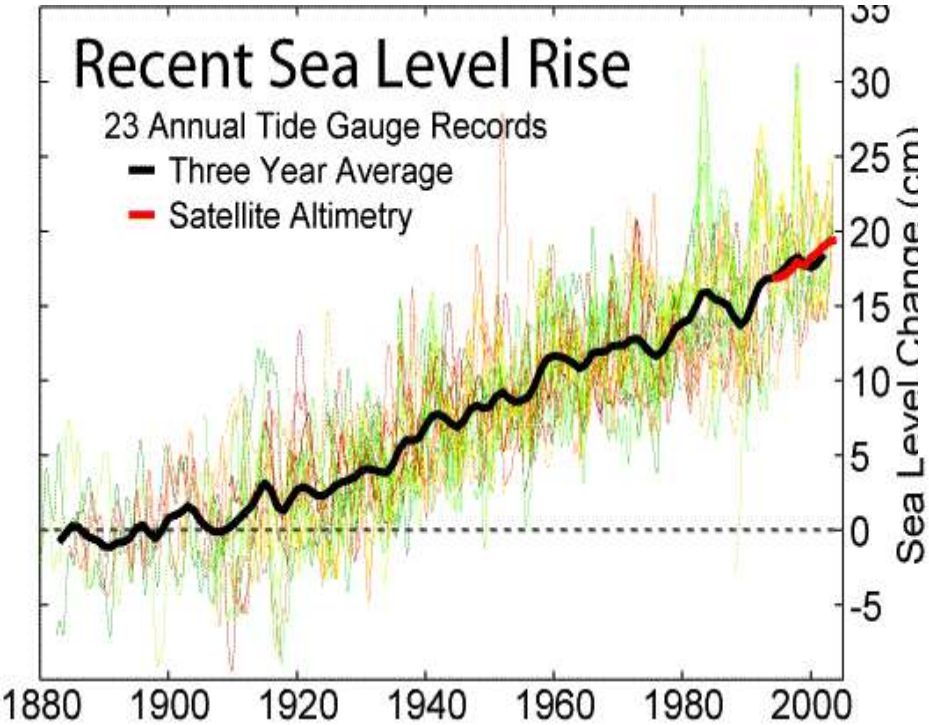
James Crabbe

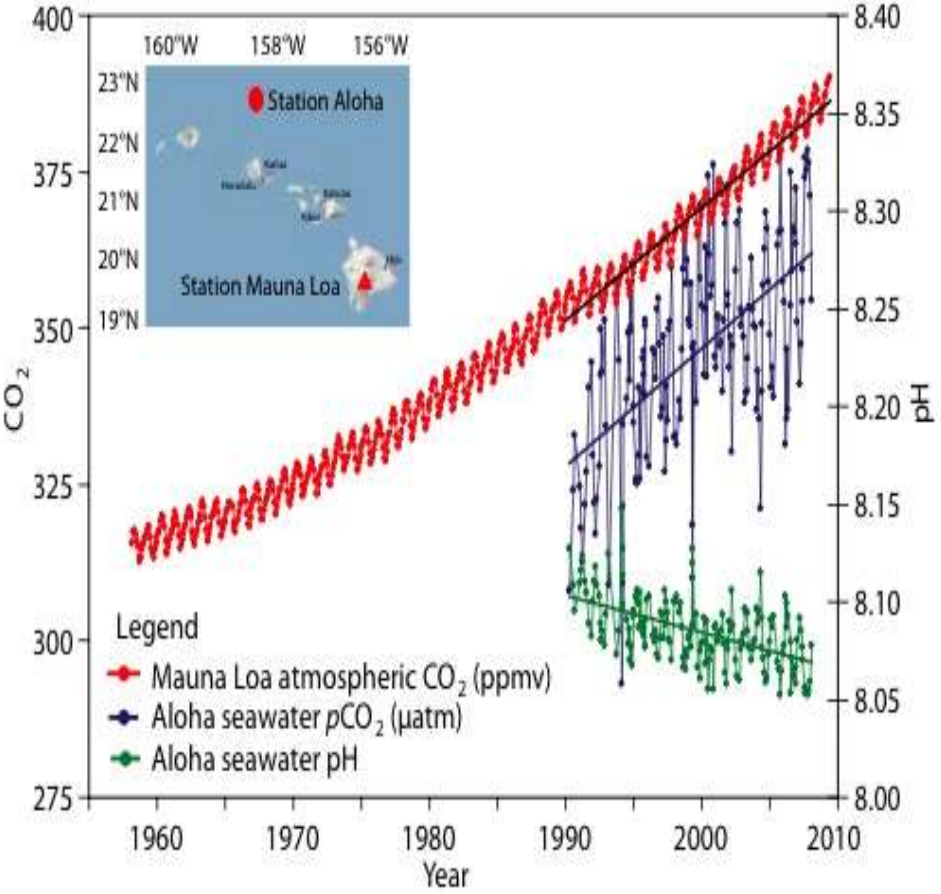
WOLFSON COLLEGE
UNIVERSITY OF OXFORD

SUMMARY

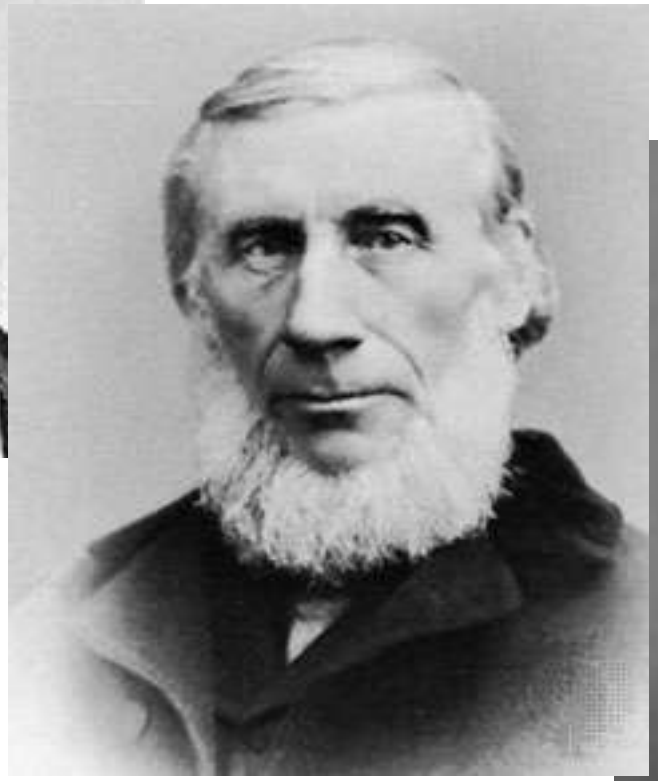
1. Climate Change
2. Coral Reefs
3. Reefs in the Caribbean
4. Reefs in Indonesia and China (Hainan)
5. From Science to Conservation
6. Geoengineering


Global Temperatures
Annual Average
Five Year Average
Temperature Anomaly (°C)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1860 1880 1900 1920 1940 1960 1980 2000


Recent Sea Level Rise
23 Annual Tide Gauge Records
Three Year Average
Satellite Altimetry
Sea Level Change (cm)
35
30
25
20
15
10
5
0
-5
1880 1900 1920 1940 1960 1980 2000

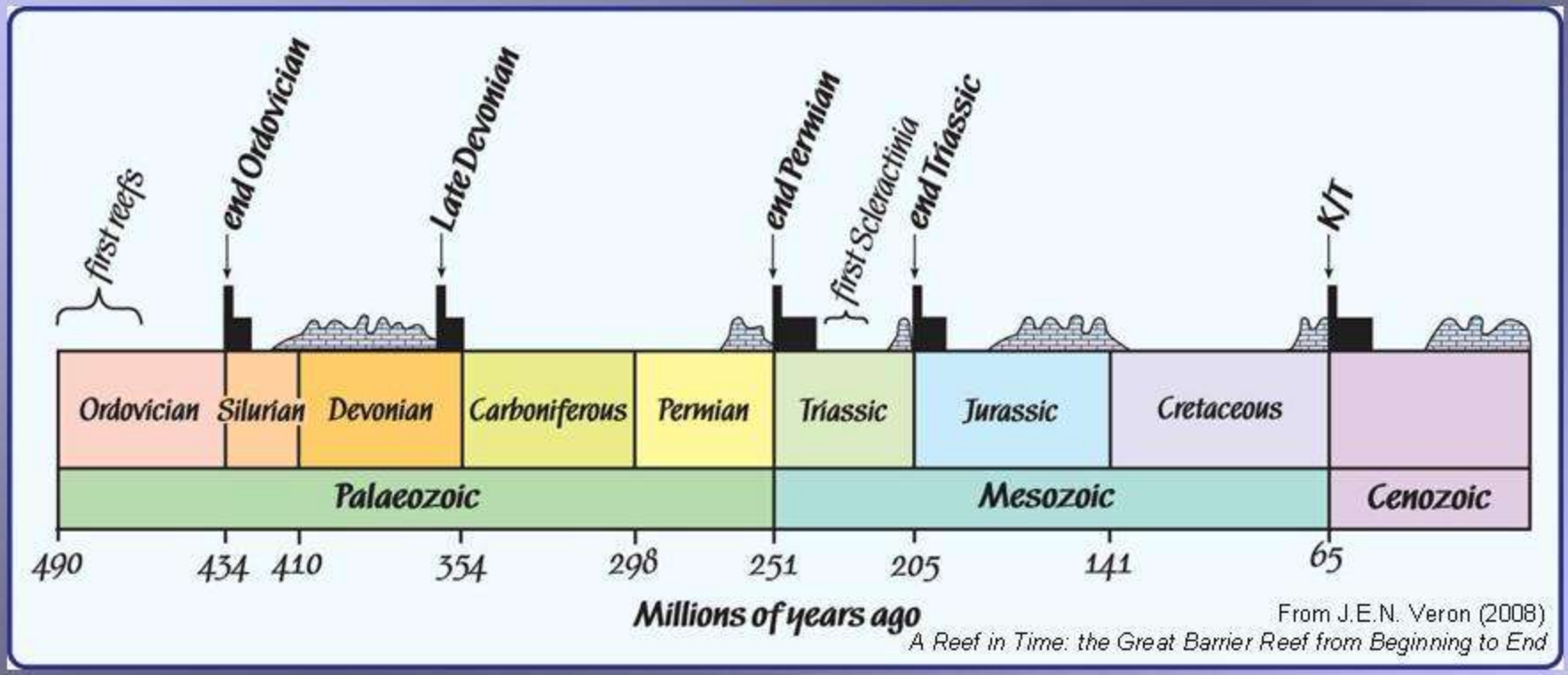

160°W
158°W
156°W
23°N
22°N
21°N
20°N
19°N
Station Aloha
Station Mauna Loa
CO_2
pH
400
375
350
325
300
275
8.40
8.35
8.30
8.25
8.20
8.15
8.10
8.05
8.00
1960 1970 1980 1990 2000 2010
Year
Legend
Mauna Loa atmospheric CO_2 (ppmv)
Aloha seawater pCO_2 (µatm)
Aloha seawater pH

Baron Jean Baptiste Joseph Fourier 1824: ‘Earth’s atmosphere acts like a bell-jar’



John Tyndall 1860s : recognised the greenhouse effect and identified the relative forcing values of different greenhouse gases.

Svante August Arrhenius 1895: ‘Carbon dioxide in atmosphere gives hothouse effect’



From J.E.N. Veron (2008)
A Reef in Time: the Great Barrier Reef from Beginning to End

Stony Corals - Scleractinia

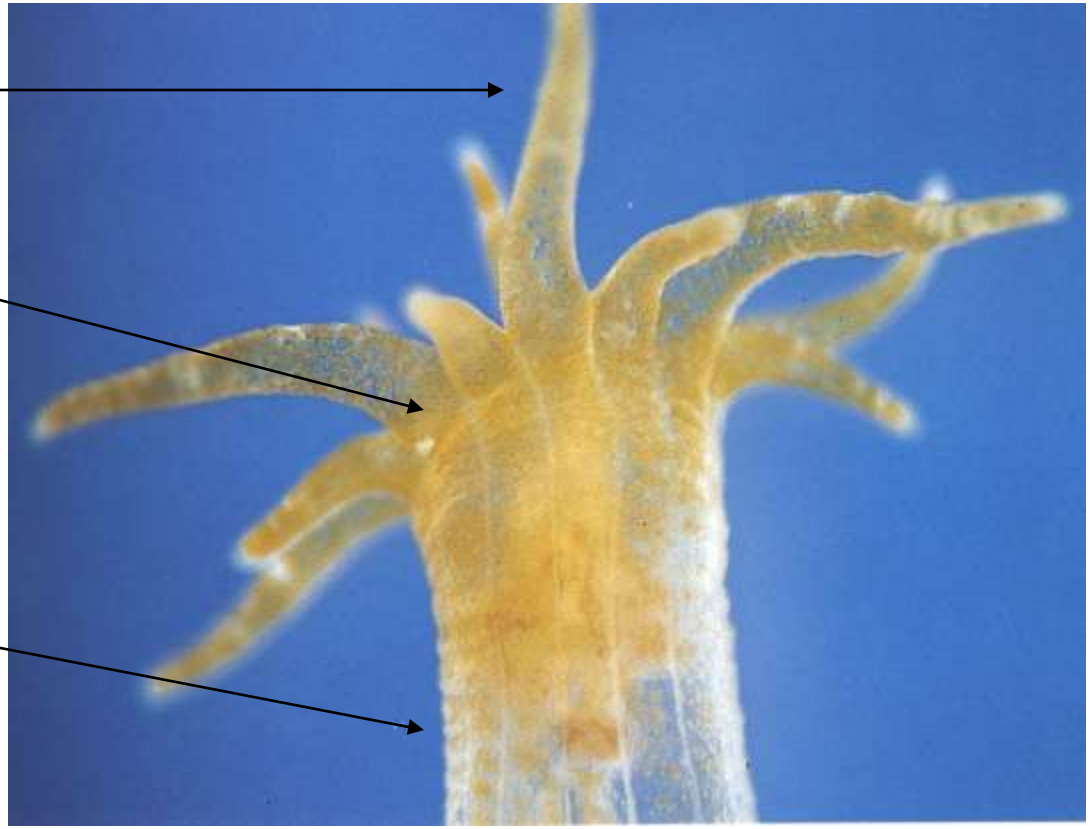
- Scleractinia (scler = hard, actinia = ray)
- Closely related to sea anemones
- Contain Algae (Zooxanthellae)
- Reef-building

SYMBIOSIS

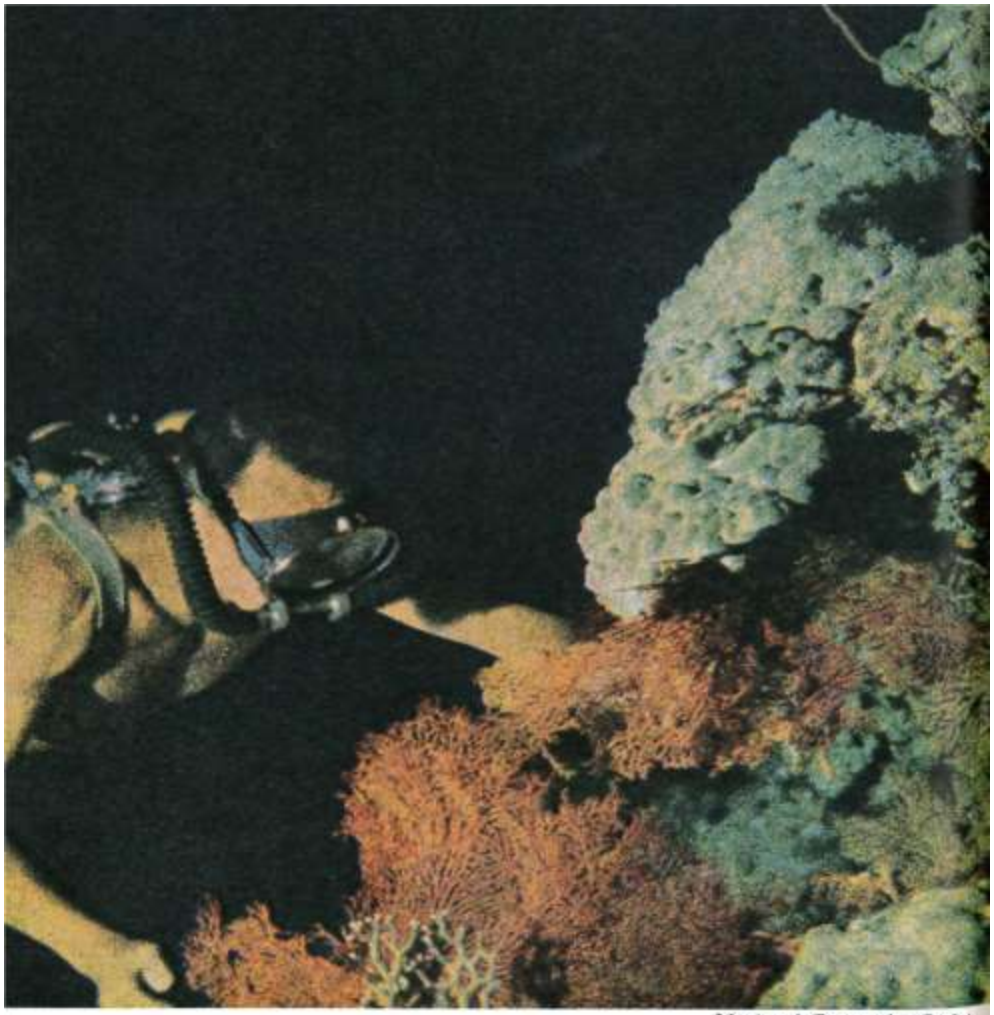
- Tentacles
- zooxanthellae

(*Symbiodinium* sp.)

- Polyp body



Above: The ancestor of our aqualung diving apparatus was Le Prieur's 1933 compressed-air cylinder. Divers could walk in shallow depths, feeding themselves air from a hand valve. In 1942 the brilliant engineer, Émile Gagnan, and I made the first completely automatic compressed-air apparatus, the aqualung. *Below:* Philippe Tailliez, of the Undersea Research Group, swims in full freedom with an aqualung, receiving breath automatically from the demand regulator.



National Geographic Society

Dumas gathers gorgonians 100 feet down. The cord shown at upper right is not from the flash-bulb reflector, but is a horny coral growth.

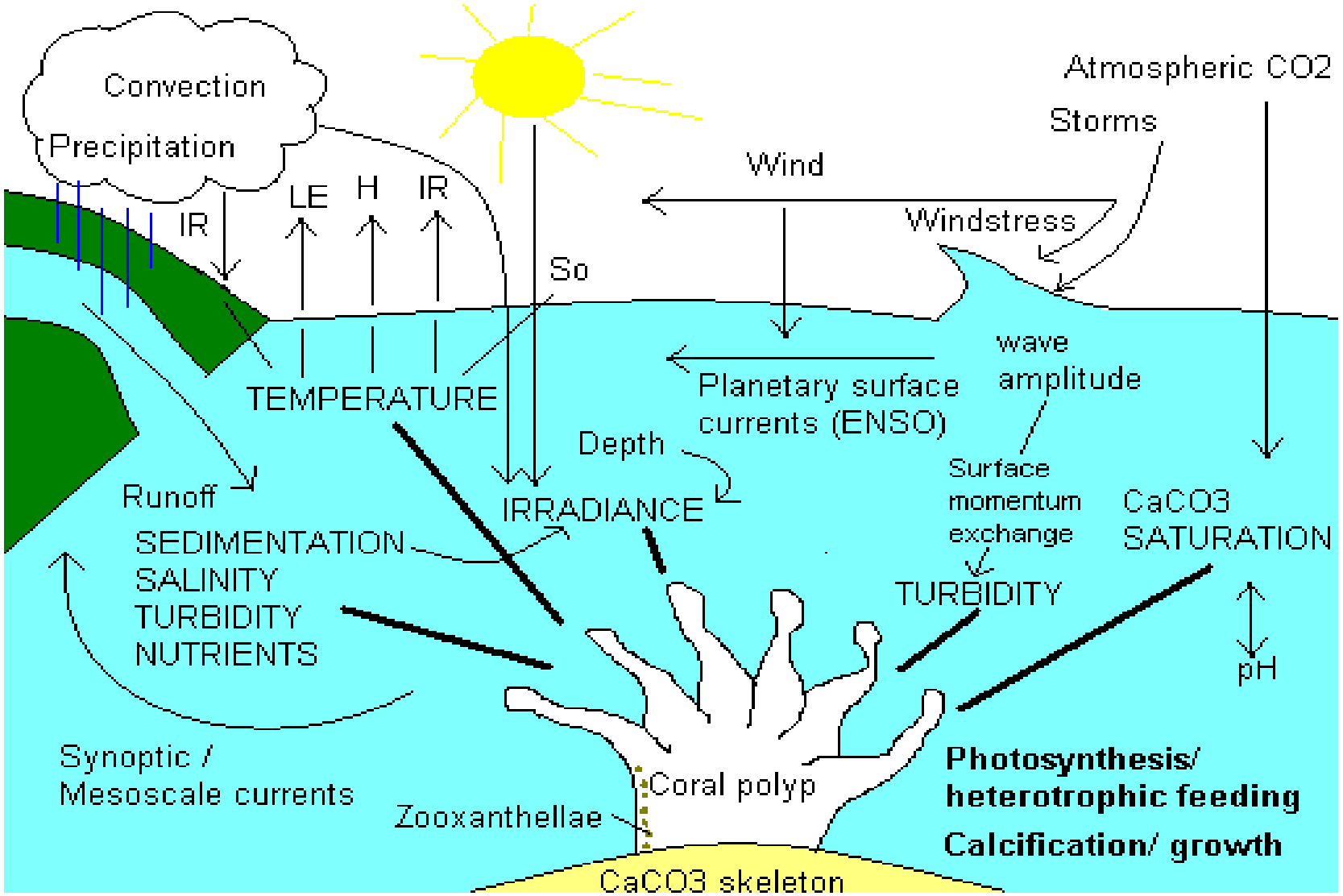
WHY ARE THEY IMPORTANT?

- valuable natural resource - high productivity rainforests of the sea – high biodiversity
- food source for millions
- source of medicines -- worth billions $$
- coastal protection from wave erosion
- source of islands & white sand beaches for tourist resorts
- 12 million SCUBA divers

Ecosystem connectivity: coral reef-seagrass-mangrove-coastal forest

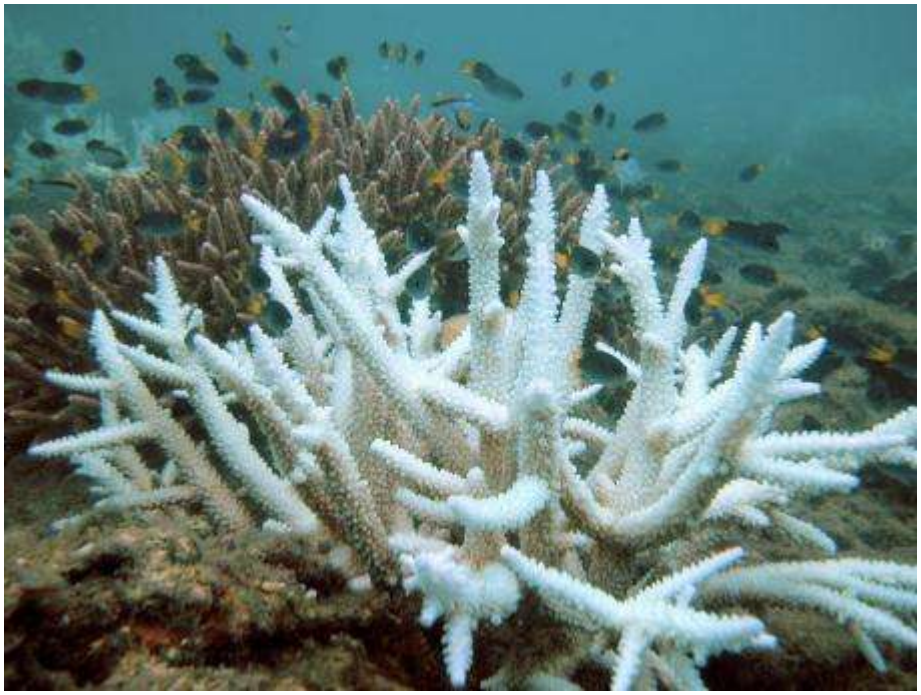
Crabbe, M.J.C. (2009) Climate change and tropical marine agriculture. *J. Experimental Botany*. In the Press.

Meteorological processes influencing tropical marine life



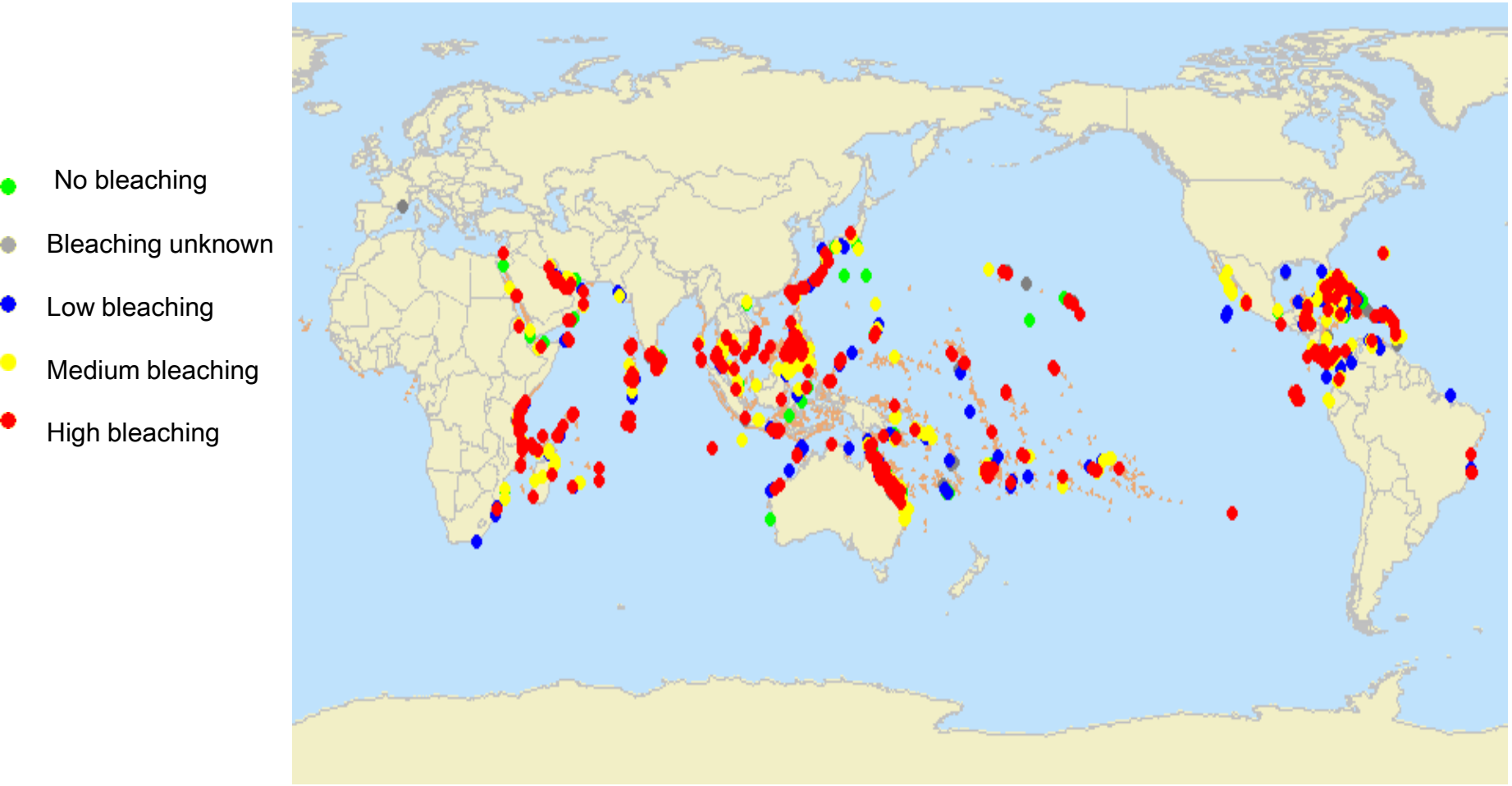
Crabbe, M.J.C., Walker, E.L.L. & Stephenson, D.B. (2008) The impact of weather and climate extremes on coral growth. In: H. Diaz & R. Murnane (Eds.) *Climate Extremes and Society*. Pp. 165-188, Cambridge University Press, Cambridge.

Coral Bleaching

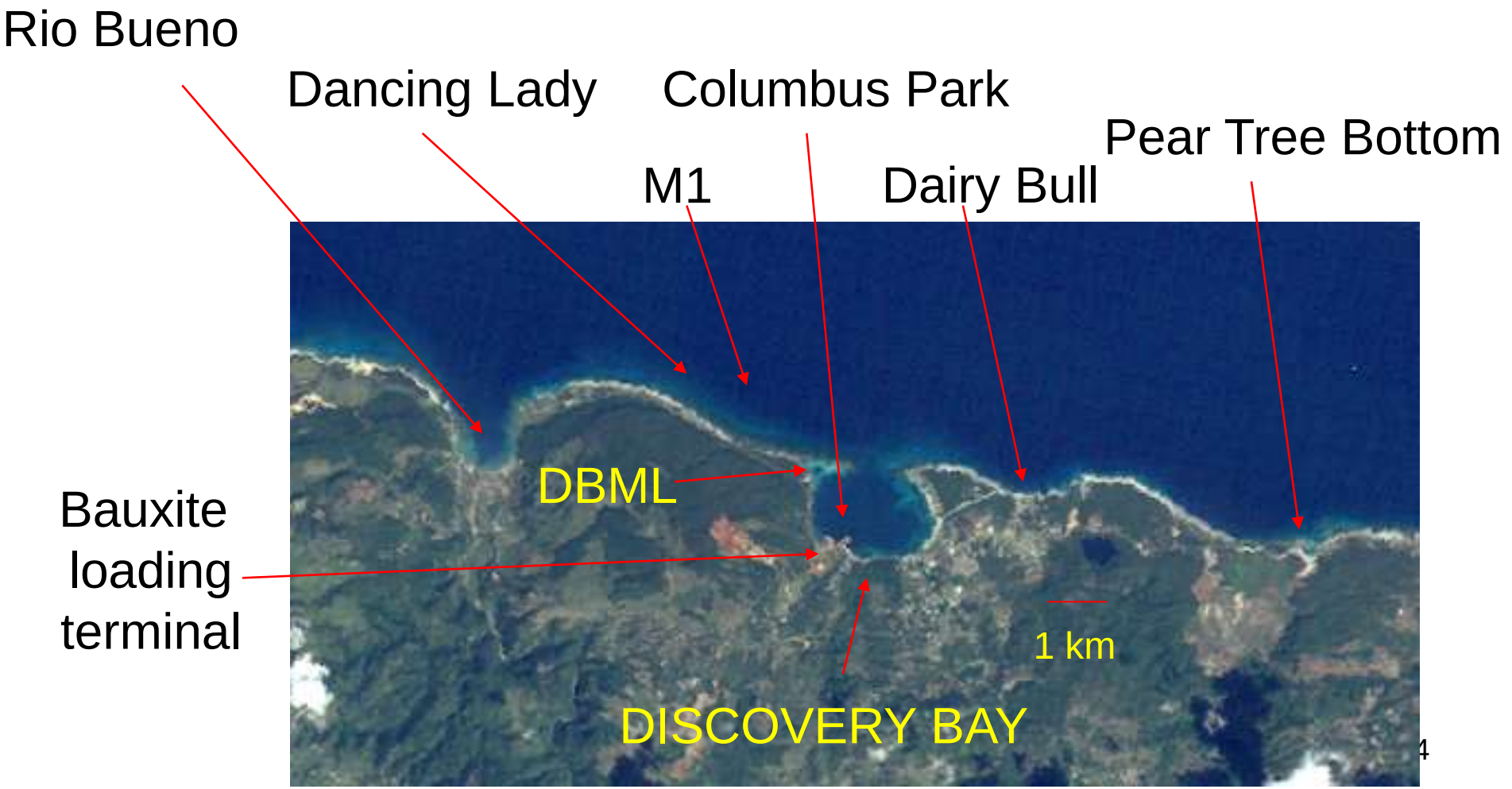


Warmer water temperatures can result in coral bleaching. When water is too warm, corals will expel the algae (zooxanthellae) living in their tissues causing the coral to turn completely white. Corals can survive a bleaching event, but they are under more stress and are subject to mortality.

World map showing levels of coral bleaching. Source: ReefBase

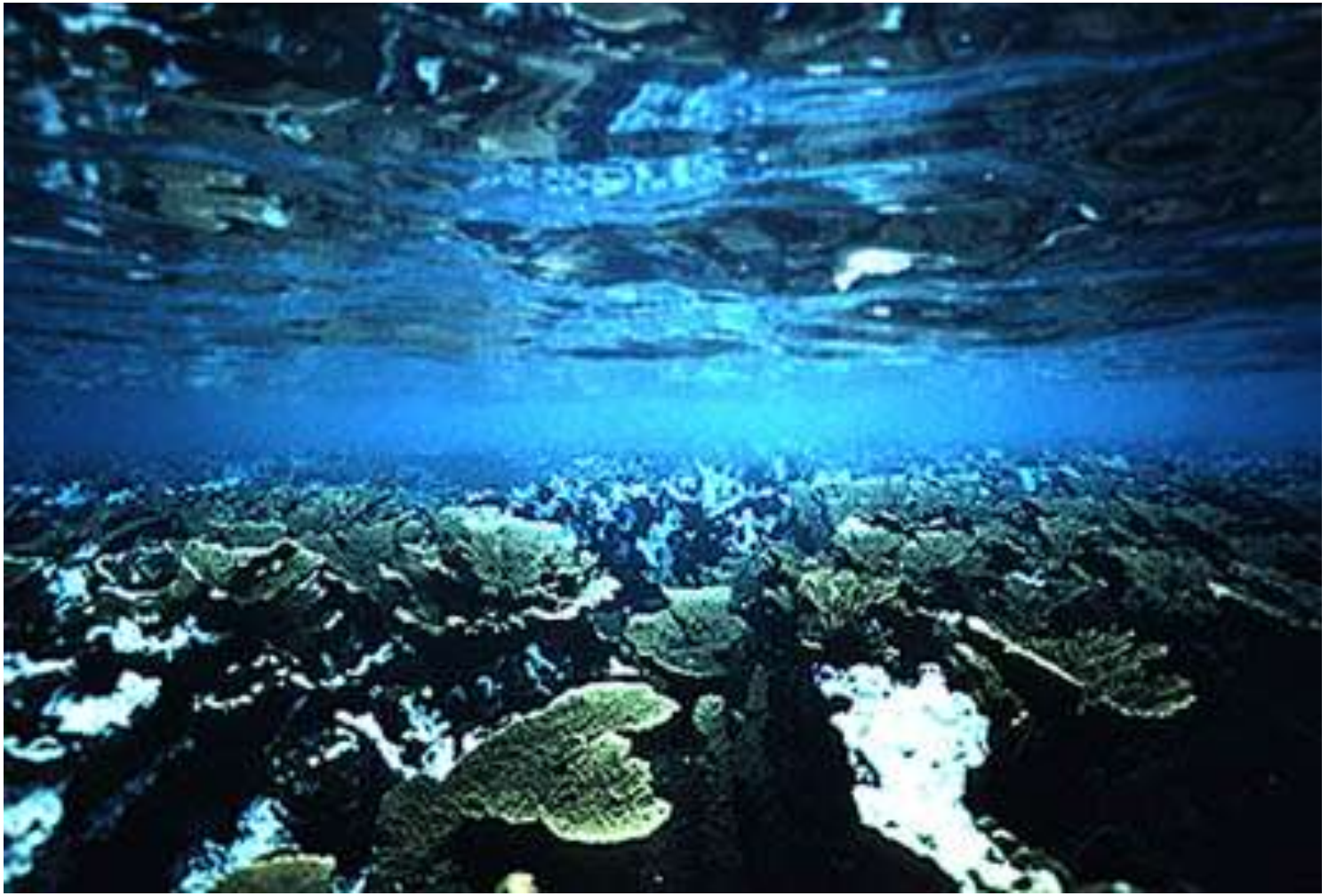


Satellite image of the Jamaican Discovery Bay study sites :



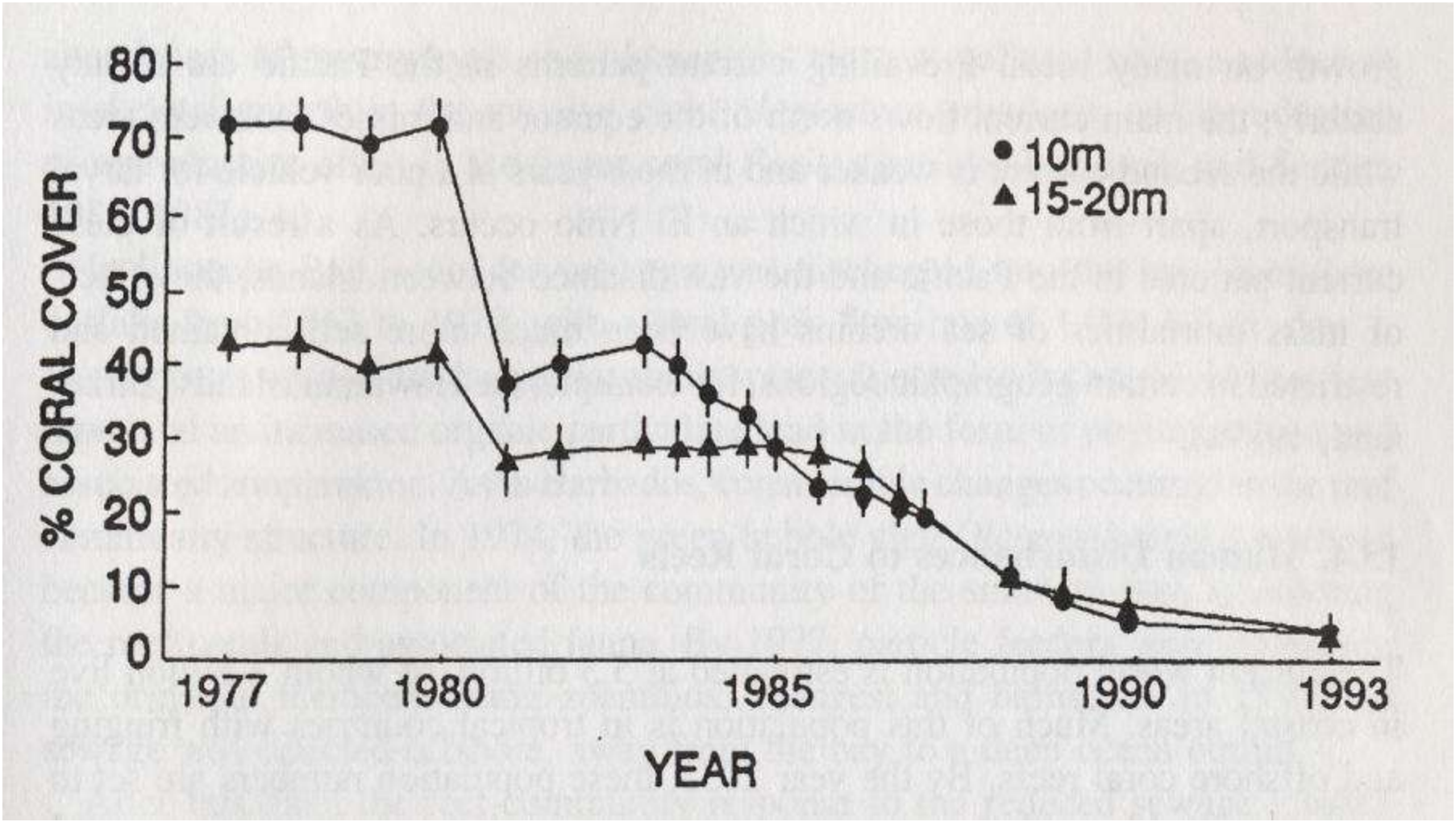
DISCOVERY BAY – WITH BAUXITE LOADING TERMINAL

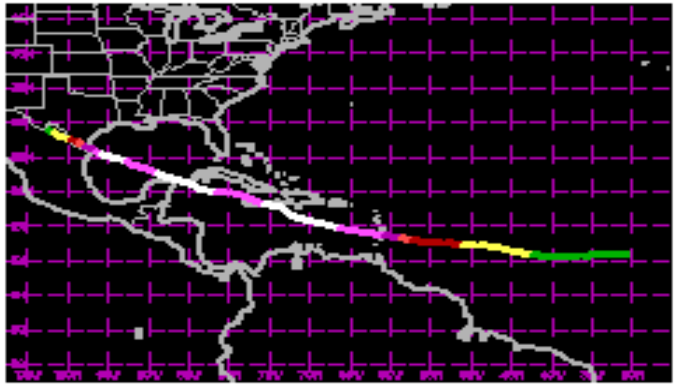
The reef crest in 1973, dominated by *Acropora palmata* (photo P. Dustan)



The reef crest in 2005

Coral cover at Rio Bueno





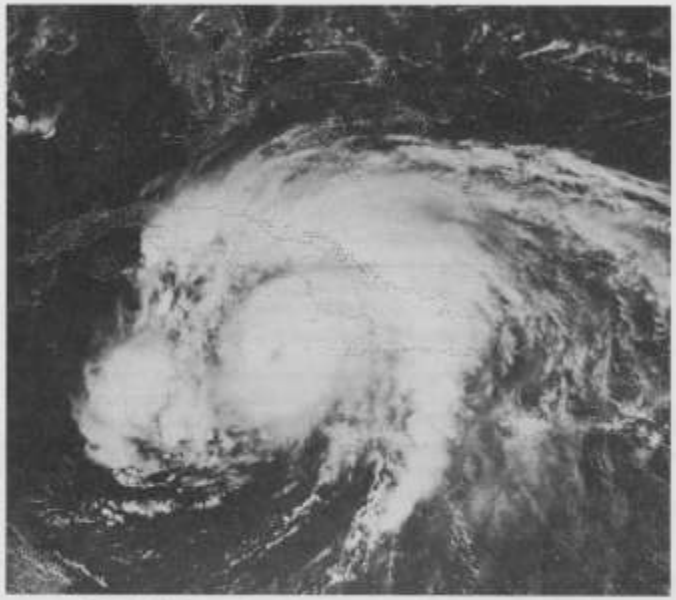


Figure 4. NOAA satellite image of Hurricane Allen on 5 August 1980.

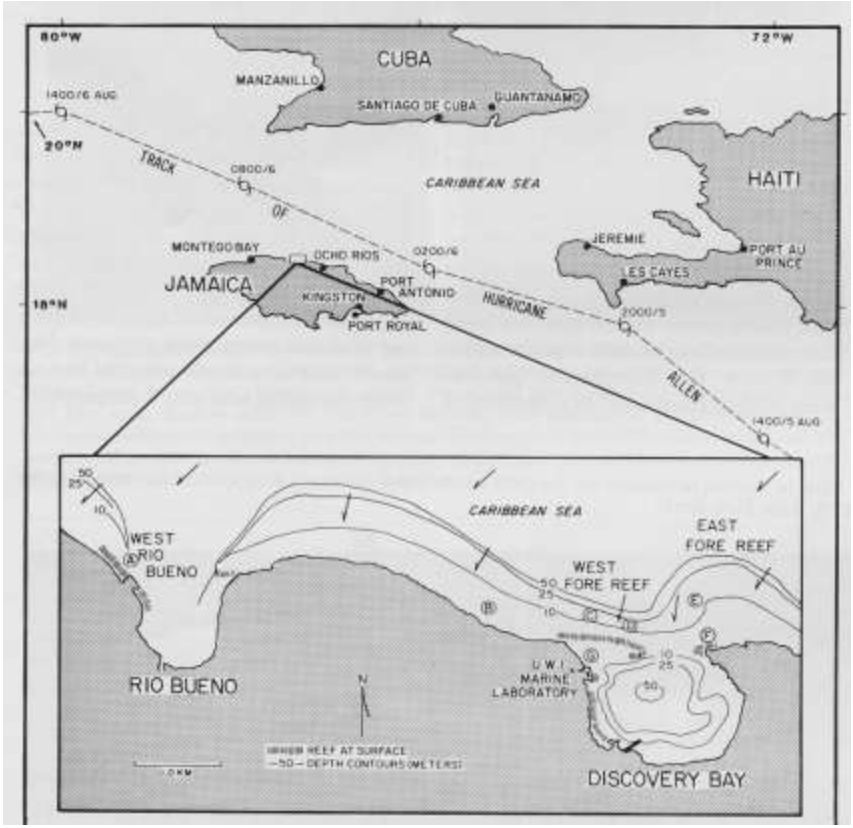
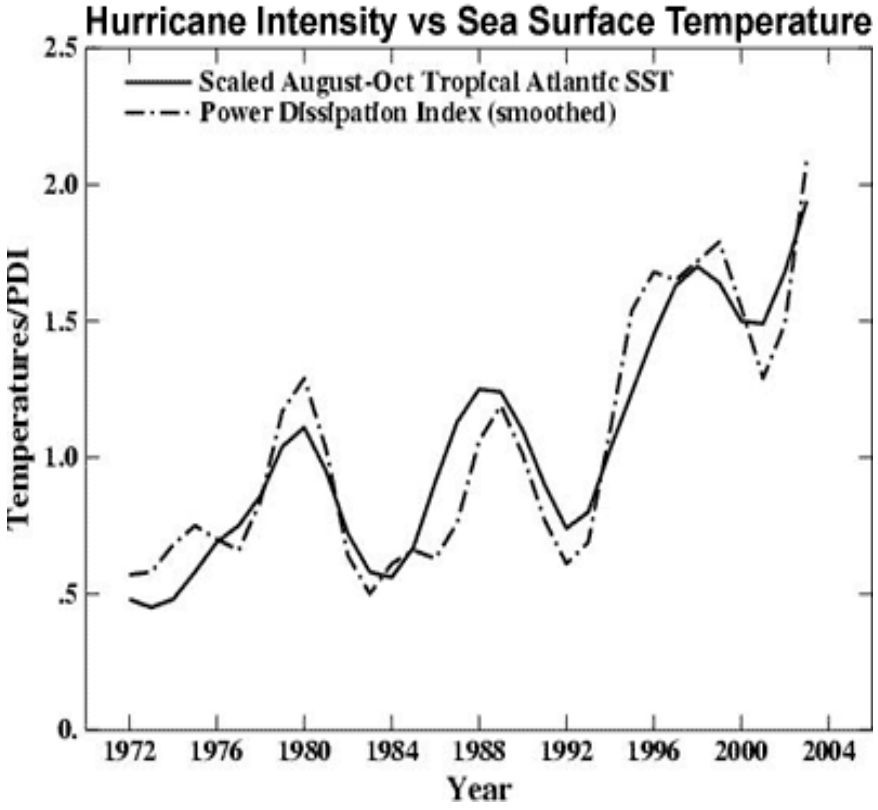
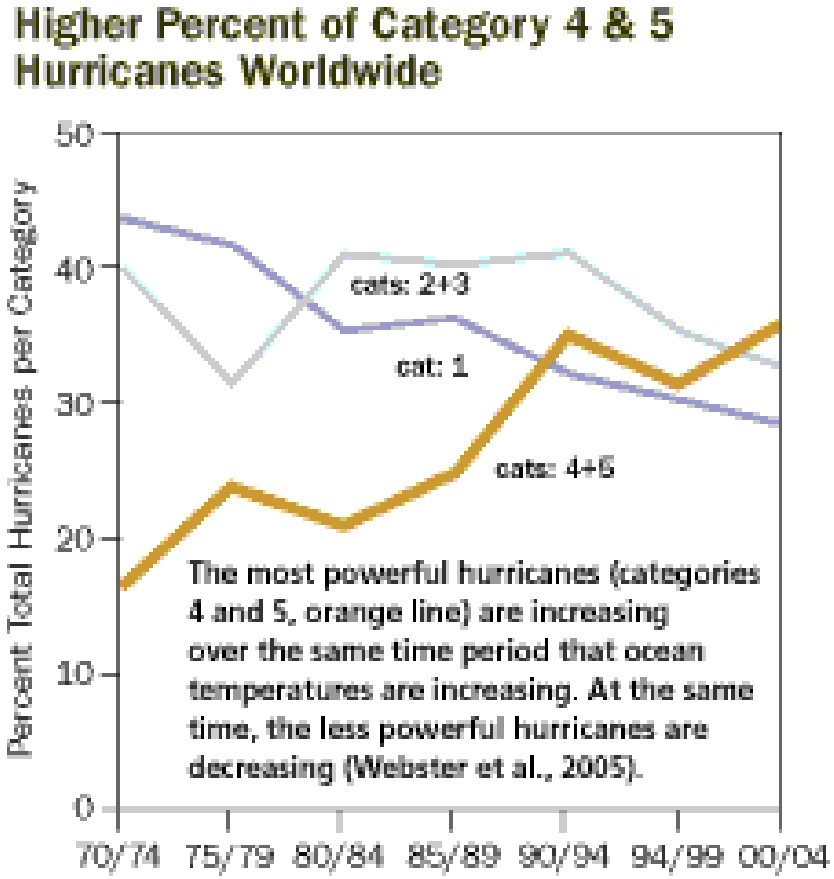


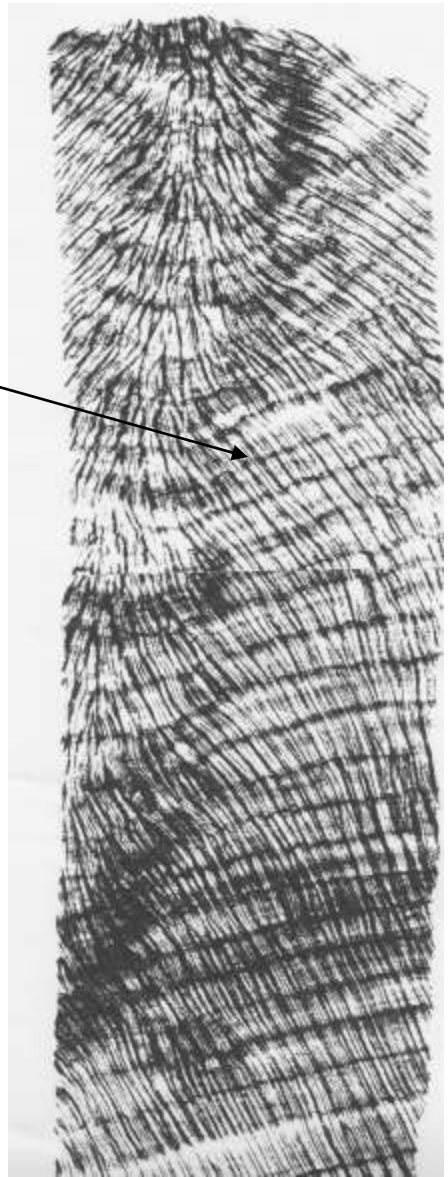
Fig. 2. Waves of Hurricane Allen breaking on East Fore Reef at Discovery Bay (Fig. 1, location E) at 0700, 6 August 1980. Wave heights were calculated to be 12 m; trees on shoreline are 15 m high. [Photograph by C.M.W.]


Hurricane Intensity vs Sea Surface Temperature
Scaled August-Oct Tropical Atlantic SST
Power Dissipation Index (smoothed)
Temperatures/PDI
2.5
2.0
1.5
1.0
.5
0.
1972
1976
1980
1984
1988
1992
1996
2000
2004
Year

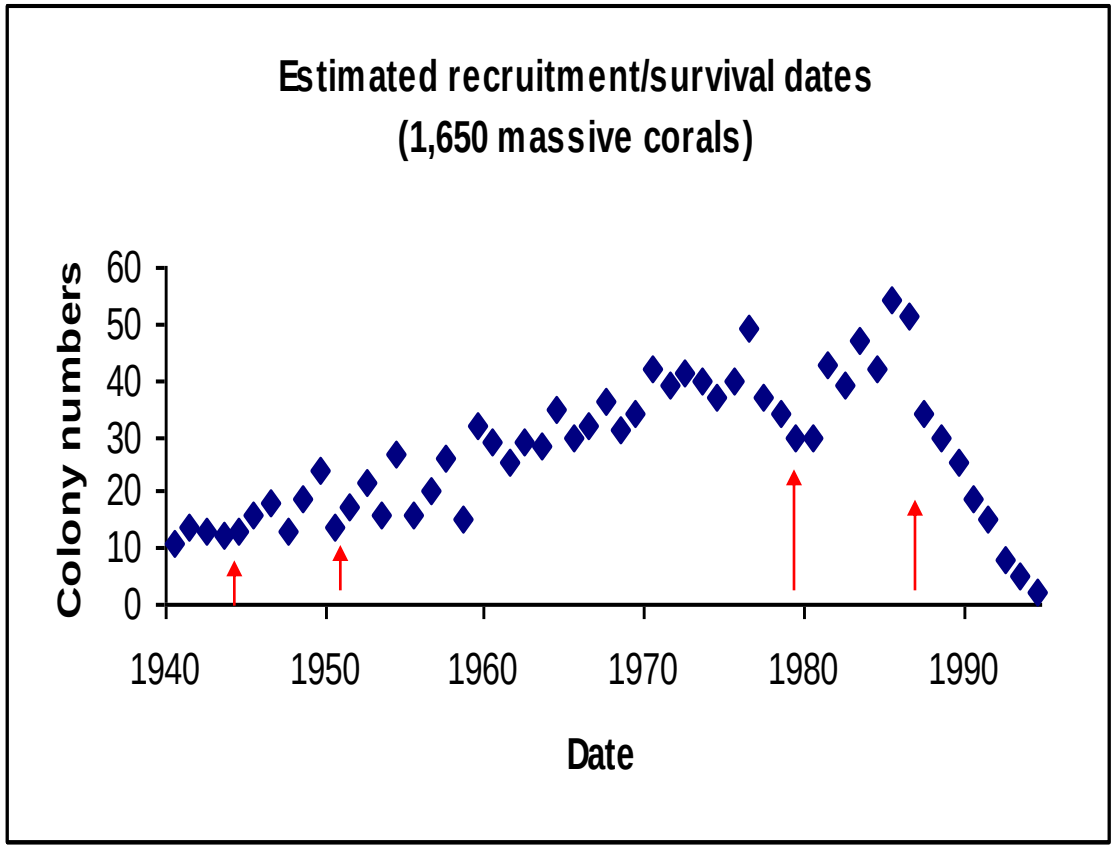

Higher Percent of Category 4 & 5 Hurricanes Worldwide
Percent Total Hurricanes per Category
50
40
30
20
10
0
cats: 2+3
cat: 1
cats: 4+5
The most powerful hurricanes (categories 4 and 5, orange line) are increasing over the same time period that ocean temperatures are increasing. At the same time, the less powerful hurricanes are decreasing (Webster et al., 2005).
70/74
75/79
80/84
85/89
90/94
94/99
00/04

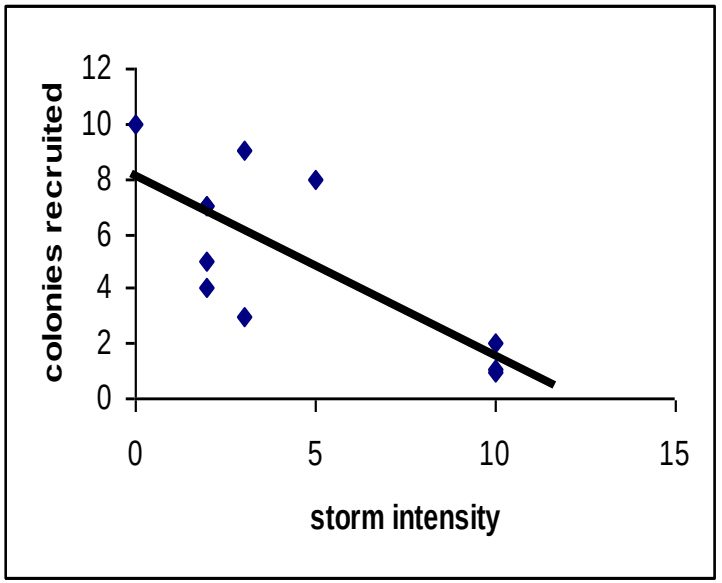
Application of computer model to coral growth data

- *Orbicella annularis* (3 individual samples) from Barbados
- Sections of corals,and X-ray photographs
- Bands refer to yearly growth



Modelling on Massive coral Recruitment/survival and storm severity



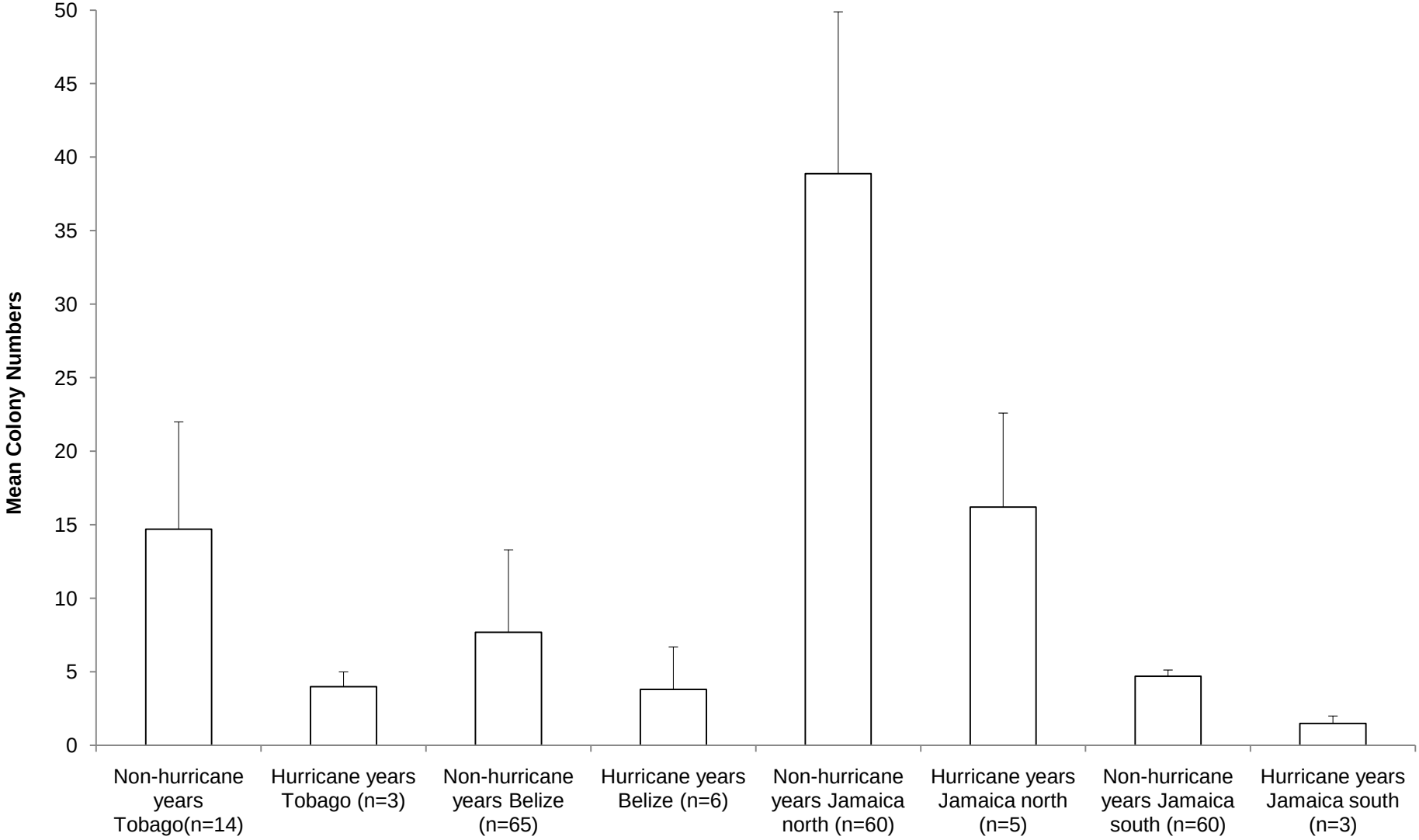


Crabbe, M.J.C., Mendes, J.M. and Warner, G.F. (2002) Lack of recruitment of non-branching corals in Discovery Bay is linked to severe storms. *Bulletin of Marine Science* **70**, 939-945.

SEVERE STORMS

- NOT ONLY DESTROY BRANCHING CORALS
- SEVERELY LIMIT NON-BRANCHING CORAL RECRUITMENT, PROBABLY OWING TO STRESS ON REPRODUCTION AND CHANGES IN TOPOGRAPHY

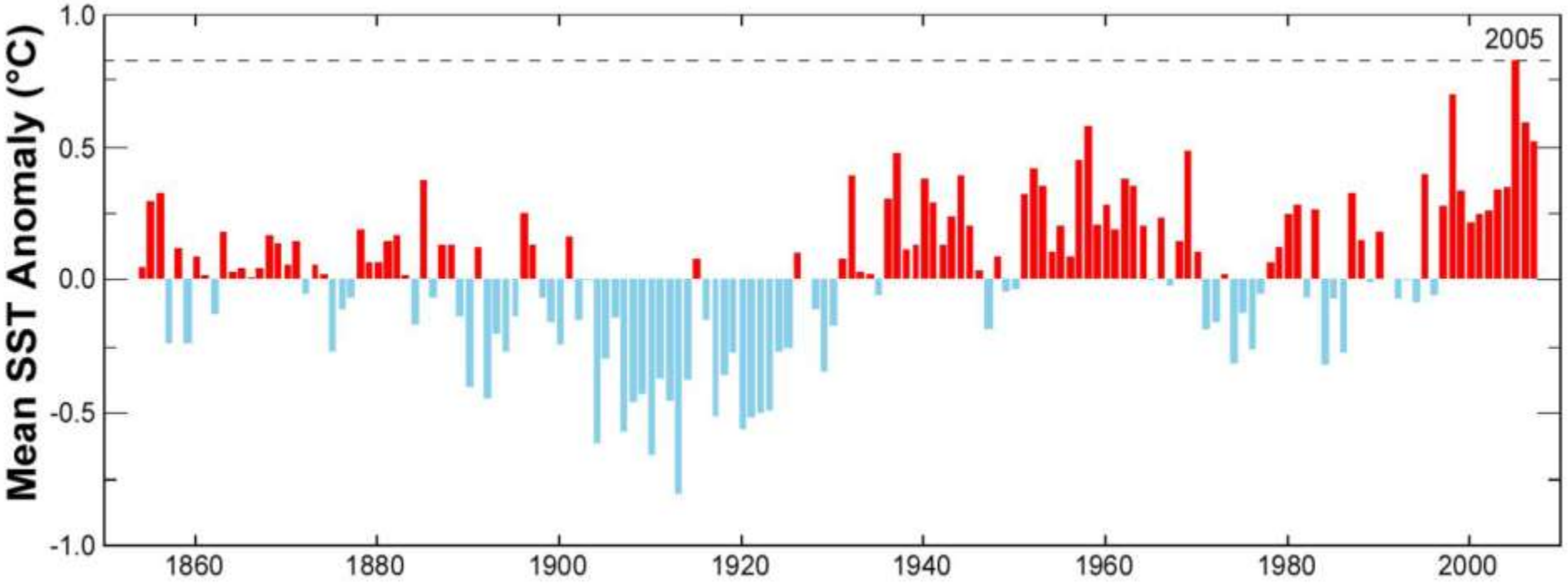
Crabbe, M.J.C., Karaviotis, S. and Smith, D.J. (2004) Preliminary comparison of three coral reef sites in the Wakatobi Marine National Park (S.E. Sulawesi, Indonesia): Estimated recruitment dates compared with Discovery Bay, Jamaica. *Bulletin of Marine Science* **74**, 469-476.



Mean number (± 1 s.d.) of coral colonies recruiting at sites in the Caribbean in hurricane years, and in years when there were no hurricanes. n refers to the number of years for each sample.

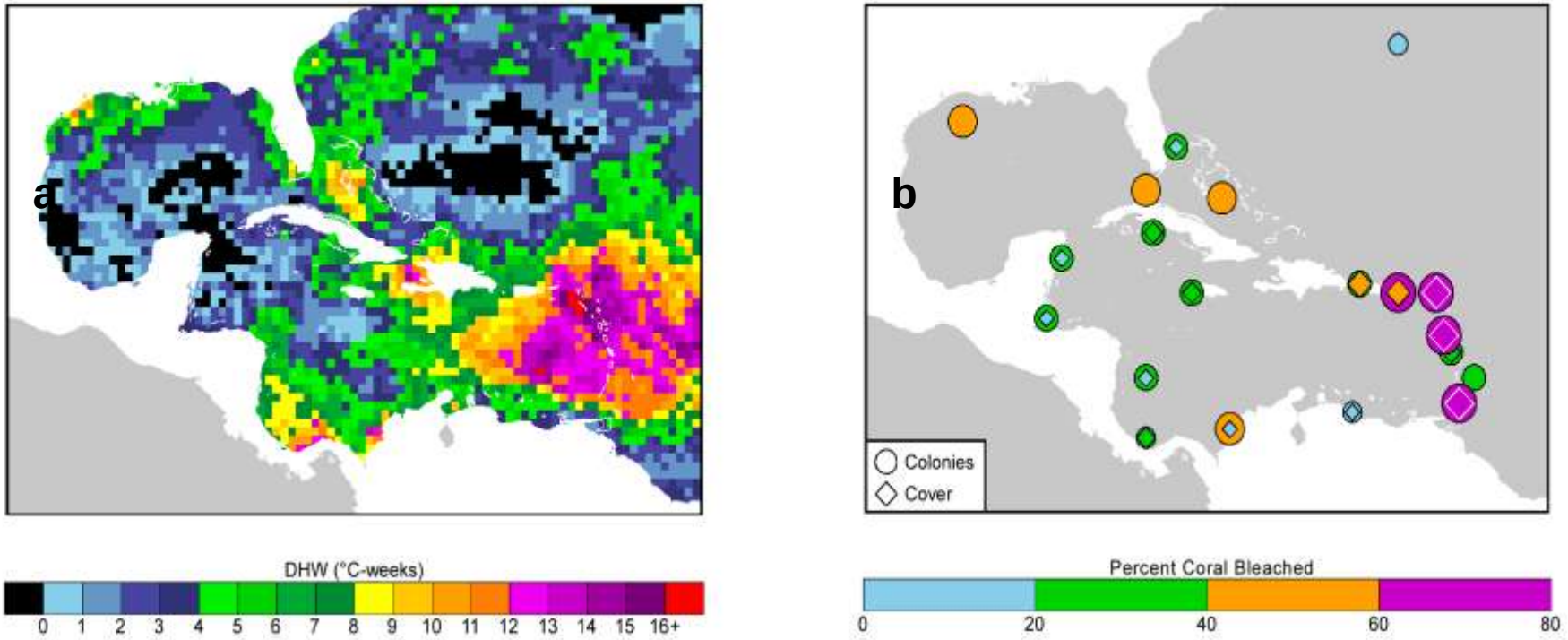
Long-term temperature trend in the Caribbean.

Temperature anomalies for 589 2.0-degree reef pixels (NOAA dataset) in the tropical Caribbean. Anomalies were plotted relative to 1901–2000. The dashed line indicates the 2005 value.

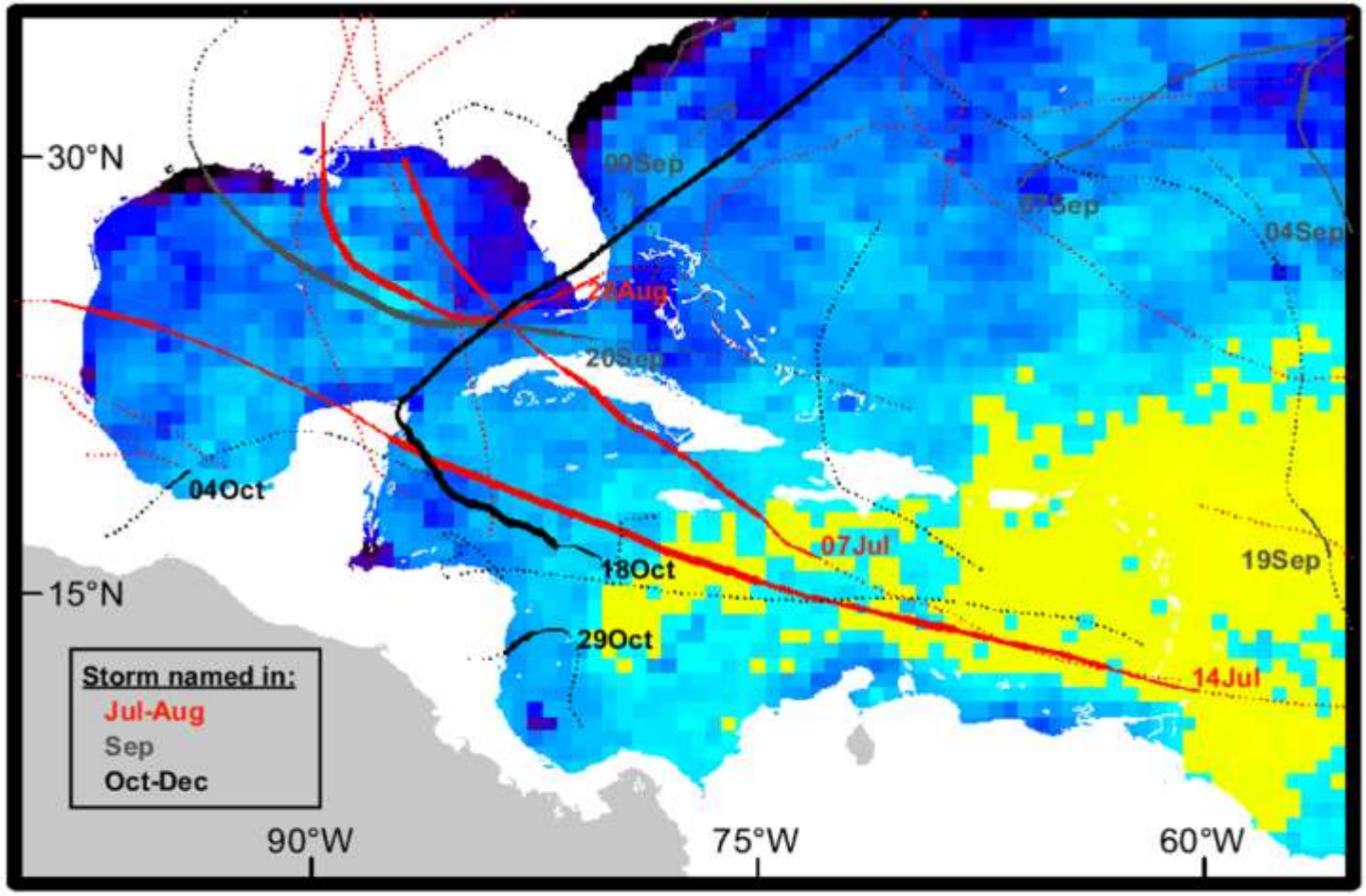


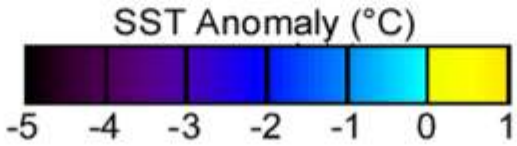
Eakin, C.M. et al. (2010) Caribbean Corals in Crisis: Record Thermal Stress, Bleaching, and Mortality in 2005. *PLOS ONE 5, e13969. doi:10.1371/journal.pone.0013969*

Thermal stress and bleaching during the 2005 Caribbean bleaching event



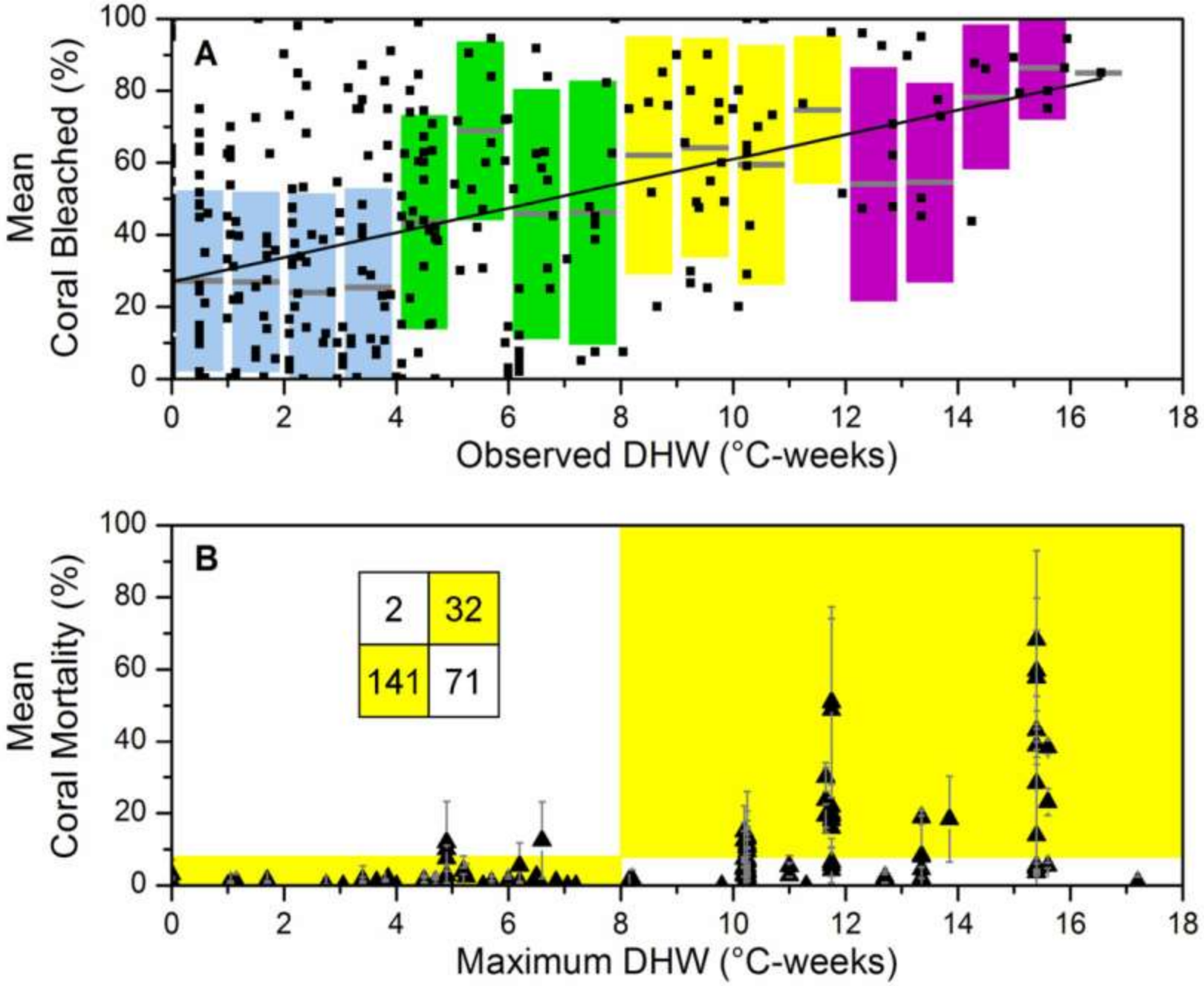
(a) Maximum NOAA Coral Reef Watch Degree Heating Week values (DHW) showing the maximum thermal stress recorded at each pixel during 2005. Values of 4 °C-weeks typically results in significant bleaching; 8 °C-weeks typically results in widespread bleaching and mortality.
(b) Jurisdiction averages of bleached percent of live coral colonies (circles) and cover (diamonds).





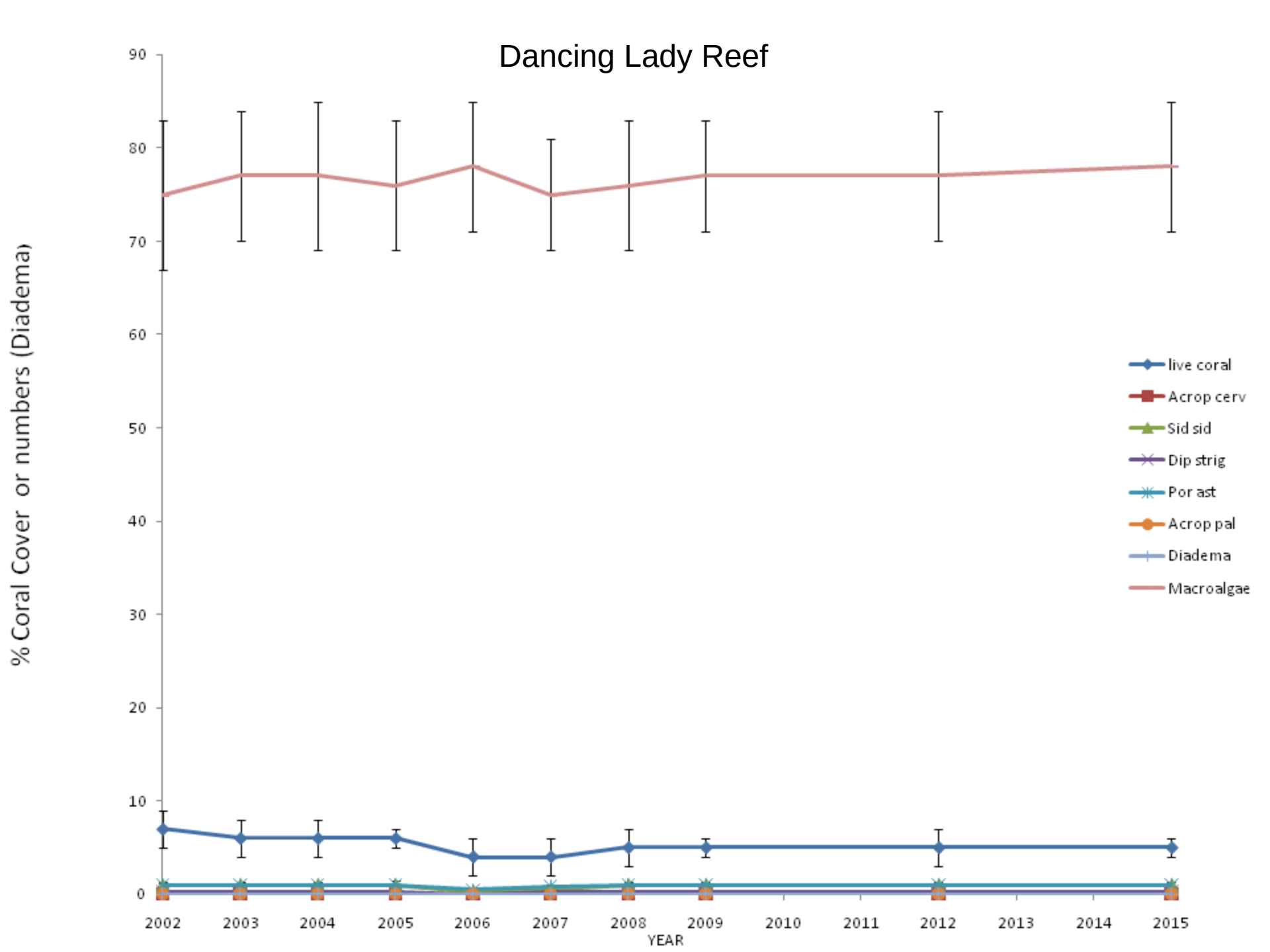
Thermal stress and hurricanes during the 2005 Caribbean bleaching event.

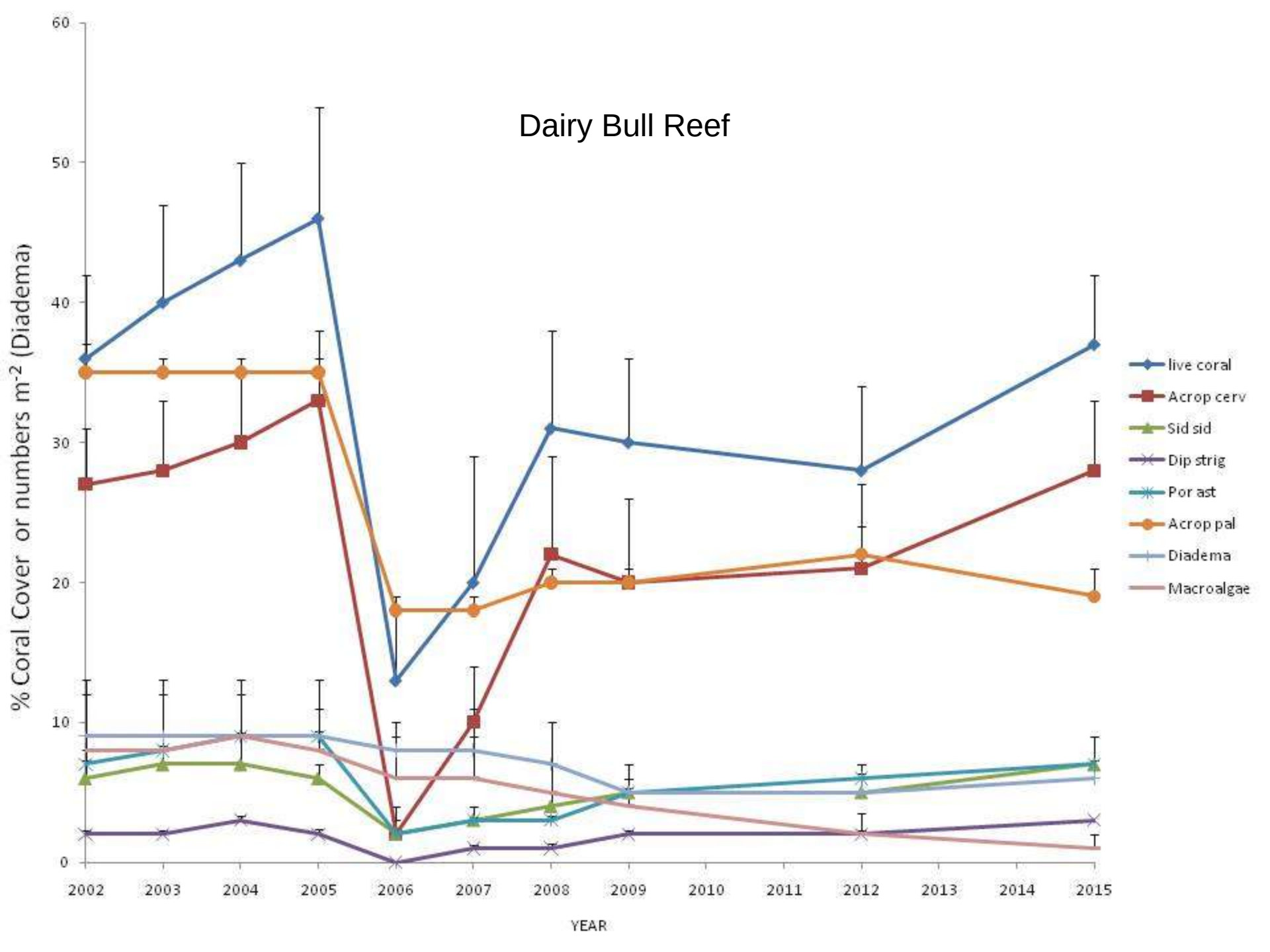
Minimum observed SST anomaly for May-December 2005, overlaid with storm tracks (solid: hurricane, thickness denotes strength category; dotted: tropical storm; red: June-August; gray: September; black: October-December).
Dates indicate initial date of hurricane formation. The large yellow region in the eastern Caribbean remained warmer than usual throughout this period.


A
Mean
Coral Bleached (%)
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
18
Observed DHW (°C-weeks)
B
Mean
Coral Mortality (%)
2
32
141
71
Maximum DHW (°C-weeks)

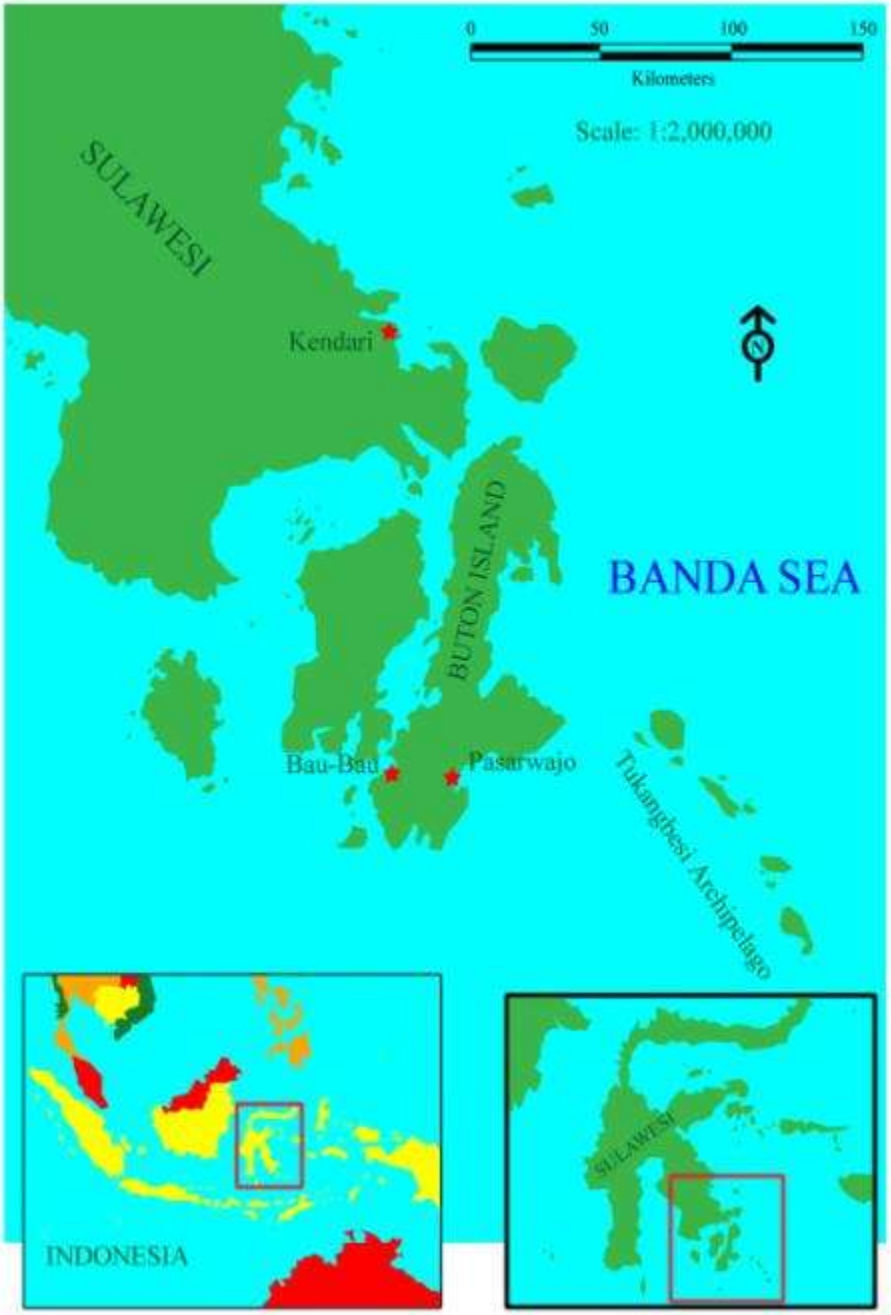
Dairy Bull Reef *A. cervicornis*
after bleaching on14th April 2006

Dairy Bull Reef *A. cervicornis*
recovery 11th August 2008

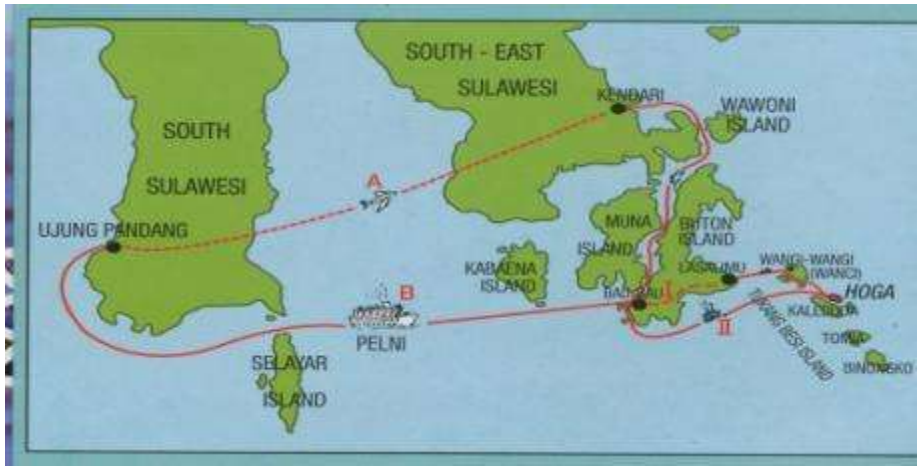

Dancing Lady Reef
% Coral Cover or numbers (Diadema)
90
80
70
60
50
40
30
20
10
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
YEAR
live coral
Acrop cerv
Sid sid
Dip strig
Por ast
Acrop pal
Diadema
Macroalgae


Dairy Bull Reef
% Coral Cover or numbers m-2 (Diadema)
60
50
40
30
20
10
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
YEAR
live coral
Acrop cerv
Sid sid
Dip strig
Por ast
Acrop pal
Diadema
Macroalgae

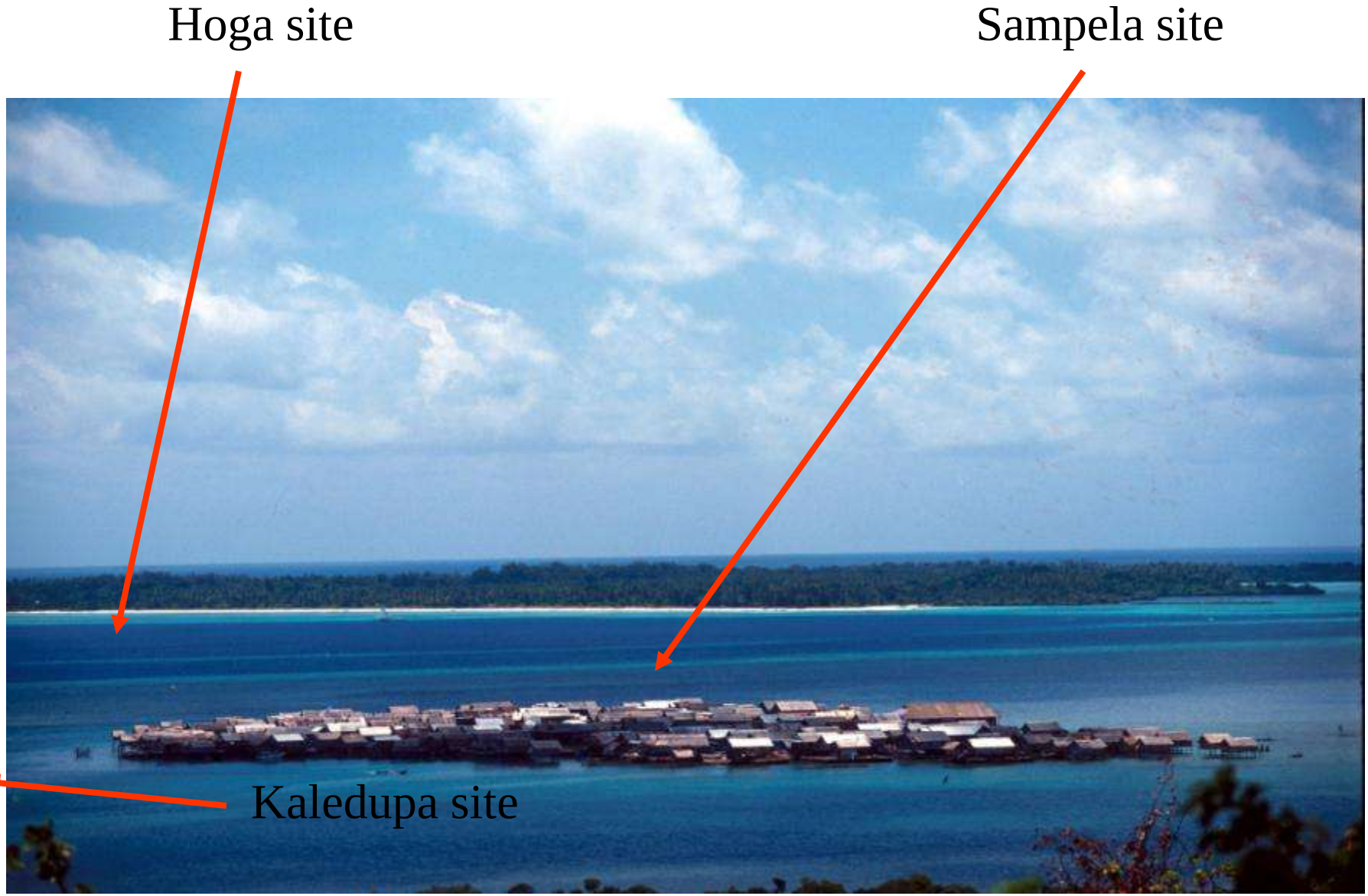
Map 1 : South-east Sulawesi and the Tukangbesi Archipelago



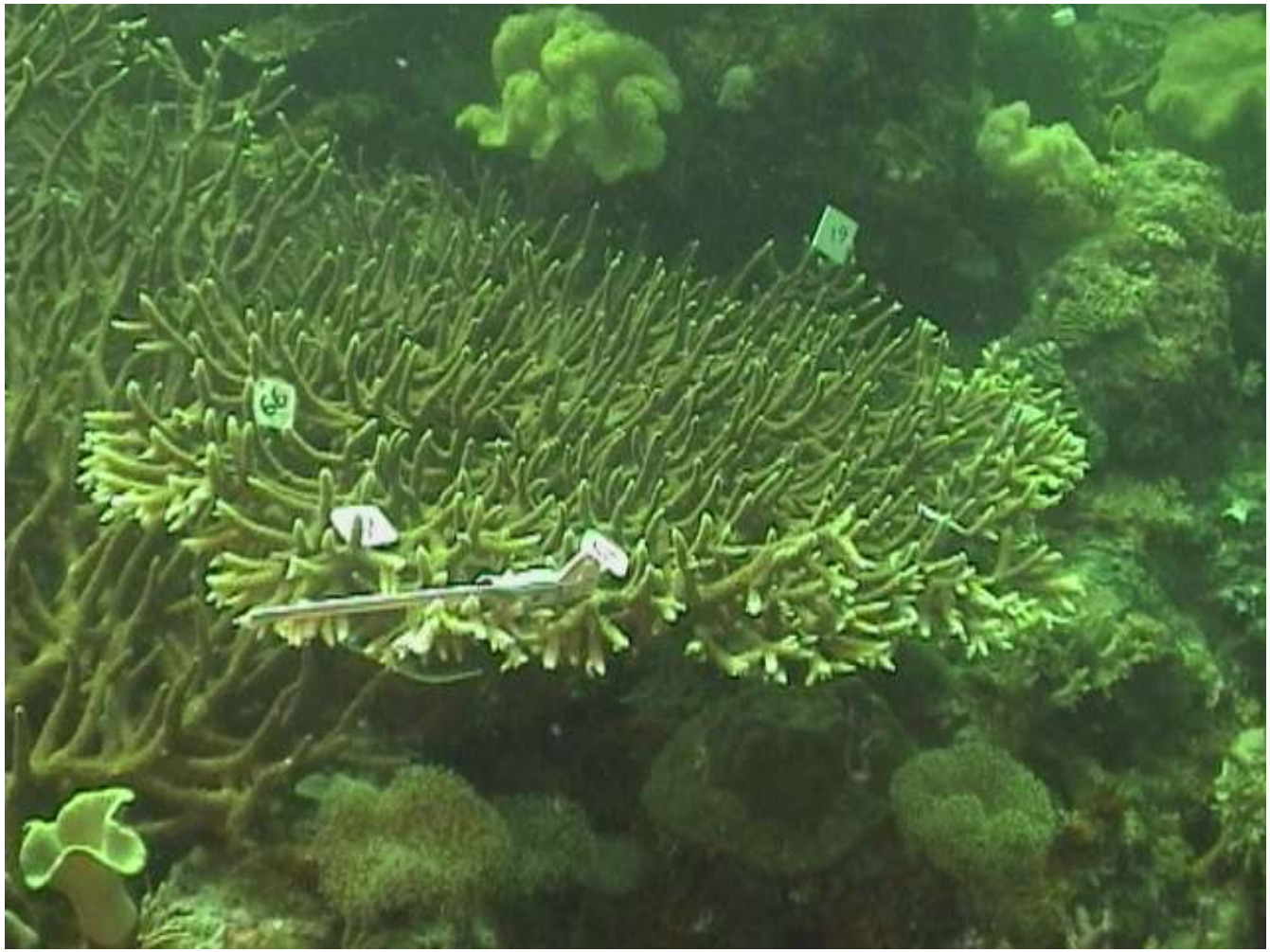
Operation Wallacea Marine Research Station on Hoga Island



Sampela village



Acropora valenciennesi colony at Kaledupa reef site, surrounded by good benthic cover. Note tags on branches, and calibration rule.



Acropora valenciennesi colony at Sampela reef site, in area of high sedimentation, surrounded by bare ground and poor benthic cover.

SAMPELA – built on corals

Collaboration with Fudan University, Shanghai


China
Hainan Province
www.PlanetWare.com
HEILONGJIANG
JILIN
INNER MONGOLIA (NEIMENGGU)
LIAONING
XINJIANG
© Baedeker
GANSU
INNER MONGOLIA (NEIMENGGU)
BEIJING (PEKING)
TIANJIN
HEBEI
NINGXIA
SHANXI
SHANDONG
QINGHAI
GANSU
SHAANXI
HENAN
JIANGSU
XIZANG (TIBET)
ANHUI
SHANGHAI
SICHUAN
HUBEI
ZHEJIANG
JIANGXI
HUNAN
GUIZHOU
FUJIAN
YUNNAN
GUANGXI
GUANGDONG
TAIW
XIANG GANG (HONGKONG)
AO MEN (MACAO)
HAINAN
The People's Republic of China
Zhonghua Renmin Gongheguo
GUANGDONG
GULF OF TONKIN
Haikou
Lingao
Xinying
Yunlong
Duowen
Xinzhou
Nanbao
Xiangu
Sanmenpo
Haitou
Nada
Longmen
Huangzhu
Mengguo
Qionghai
HAINAN
Baoban
Bo'ao
Dongfang
Yinggen
Hele
Gancheng
Wanning
Tongshen
Baoyou
Baoting
Zhizhong
Foluo
SOUTH CHINA SEA
Lingshui
Jiusuo
Xincun
Yacheng
Sanya

Coastal development around Sanya

SCIENCE TO CONSERVATION:

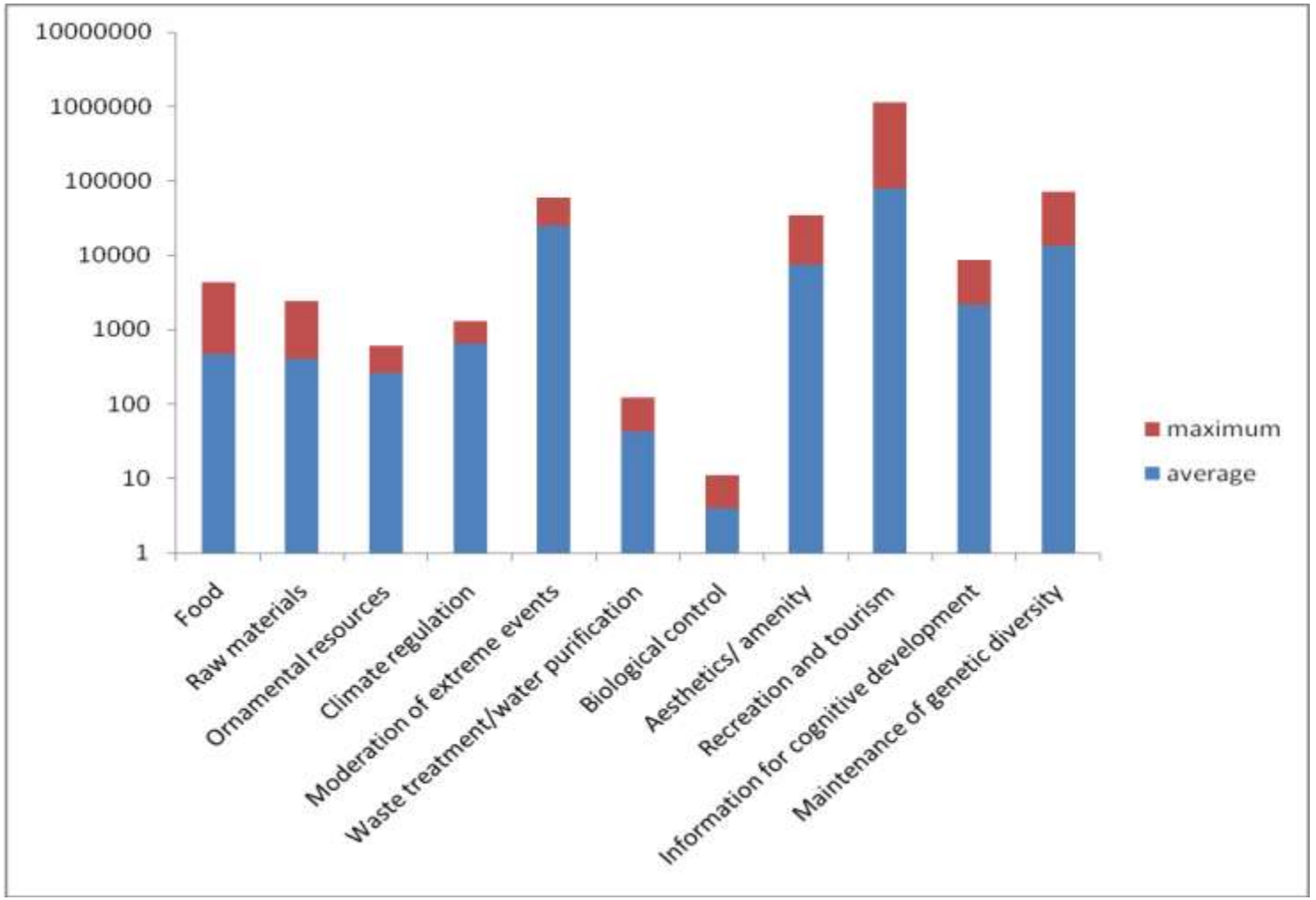
from science to capacity building and policy development

- Integrate scientific knowledge and conservation science into policy that directly benefits all the stakeholders, from Governments to local fisherfolk and their families.

Crabbe, M.J.C., et al. (2010)
Is capacity building important in policy development for sustainability?
A case study using action plans for sustainable Marine Protected Areas in Belize.
Society and Natural Resources. **23**, 181-190.

Economic benefits from ecosystem services for coral reef ecosystems.

Values are in US$ / ha / year, on a logarithmic scale,
and indicate the average value and the maximum value



TEEB – The Economics of Ecosystems and Biodiversity for national and international policymakers – Summary: Responding to the value of nature. **2009** pp.47.

Burke, L.; Selig, E.; Spalding, M. Reefs at risk in southeast Asia. Worl Resources Institute (WRI), Washington, DC, USA. Online at: www.wri.org.

The future – Community involvement !

Geoengineering

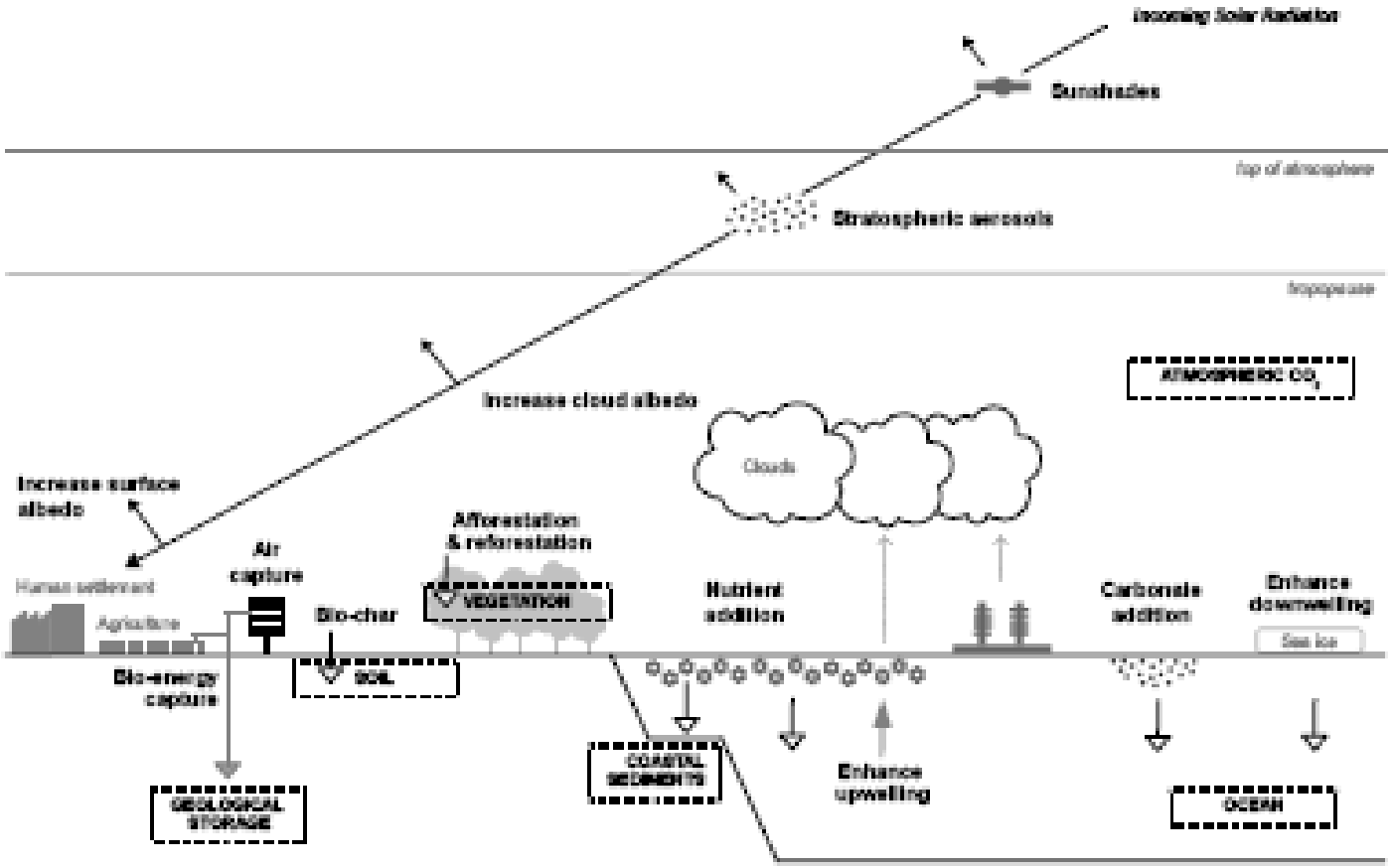
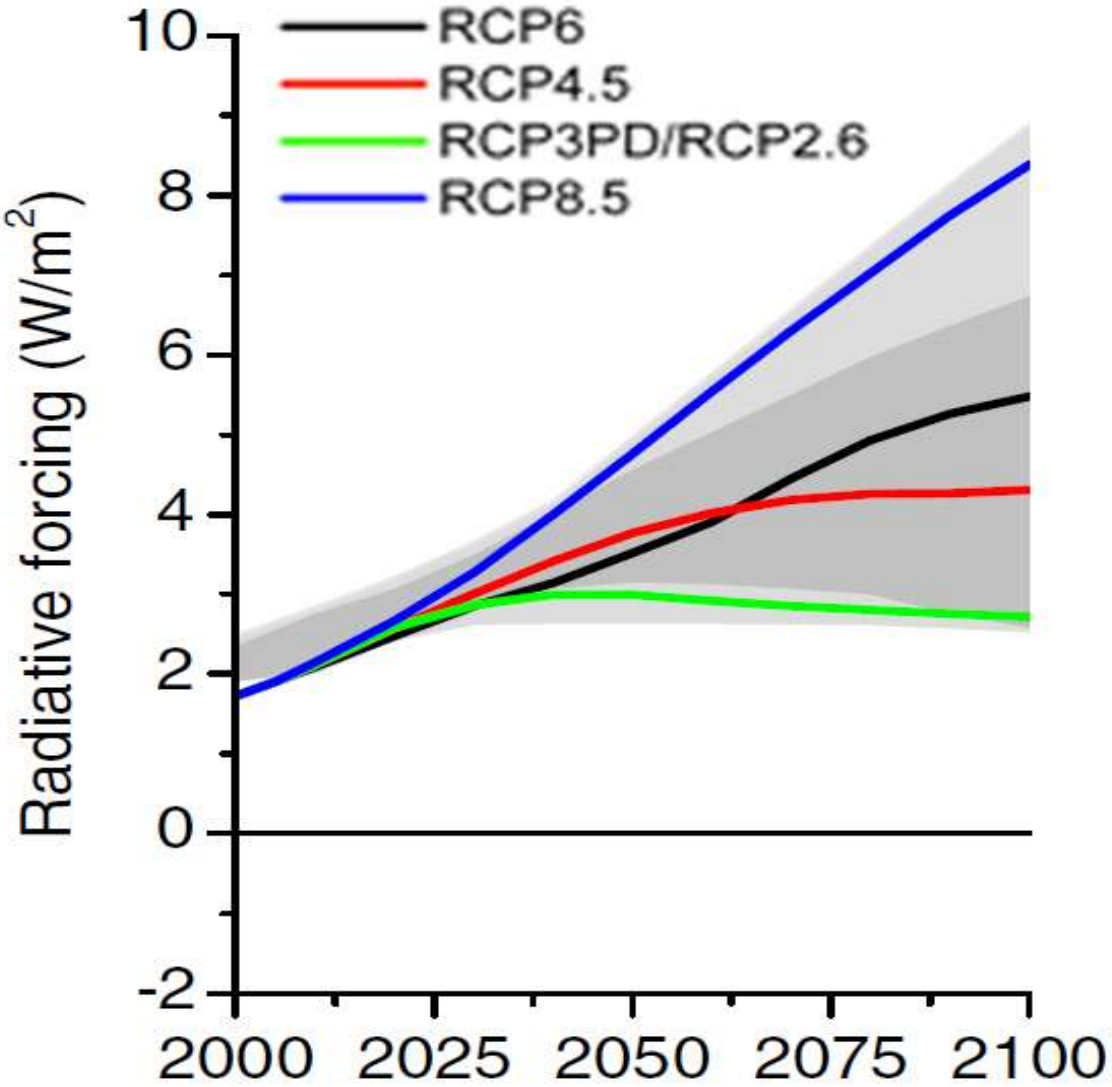


Fig. 1. Schematic overview of the climate geoengineering proposals considered. Black arrowheads indicate shortwave radiation, white arrowheads indicate enhancement of natural flows of carbon, grey downward arrow indicates engineered flow of carbon, grey upward arrow indicates engineered flow of water, dotted vertical arrows illustrate sources of cloud condensation nuclei, and dashed boxes indicate carbon stores. From Vaughan and Lenton (2009), not to scale.

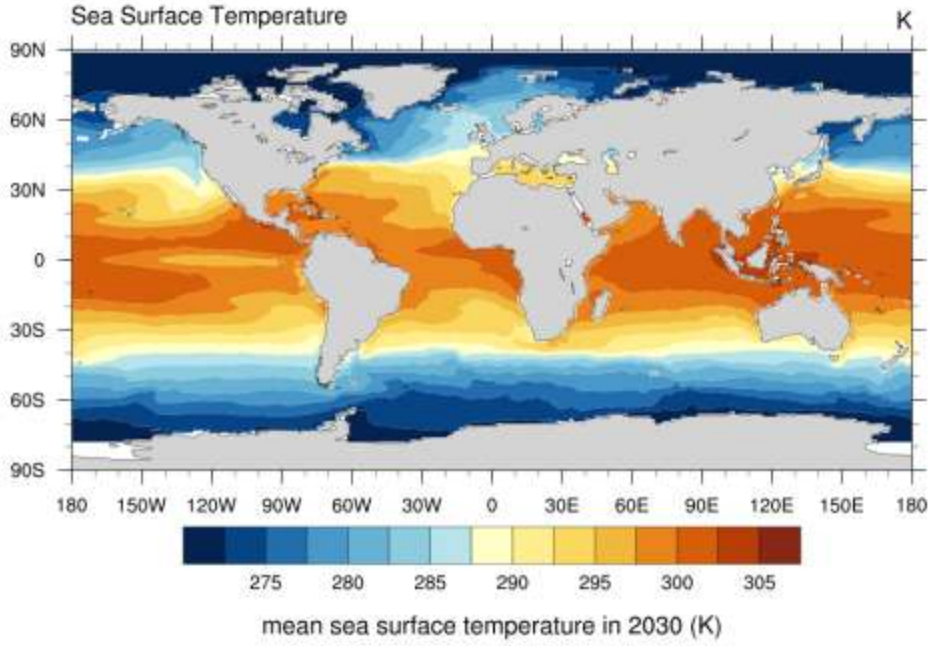
REPRESENTATIVE CONCENTRATION PATHWAYS (RCPs)

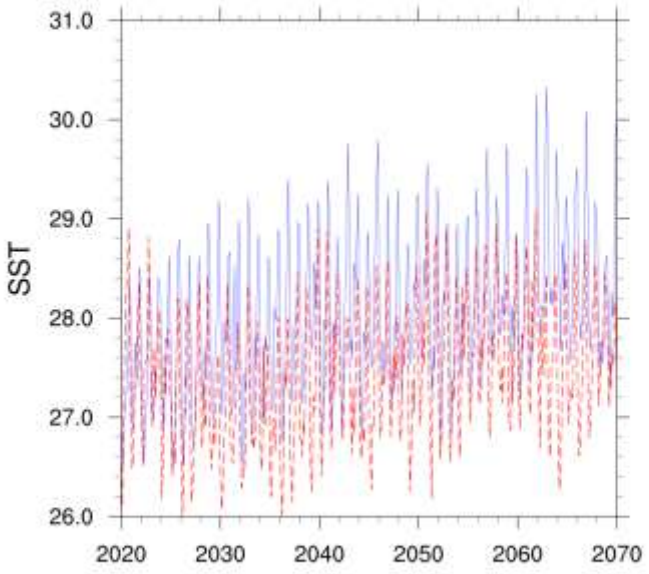
(cumulative measure of human emissions of GHGs from all sources expressed in Watts per square meter) pathway and level by 2100.

From van Vuuren et al (2011) The light grey area captures 98% of the range in previous IAM scenarios, and dark grey represents 90% of the range.



Mean sea surface temperature (and red lines) in 2030 after ten years of aerosol geoengineering ((injection of 5 Tg SO_2 per year into stratosphere since 2020). Blue line = RCP4.5 Scenario.





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CONSERVATION INTERNATIONAL

Time past and time future
Allow but a little consciousness –

T. S. Eliot, “Little Gidding,” *The Four Quartets*

THANK YOU