Effect of elevated CO_2 on the cycling of organic and inorganic carbon on coral reefs

Chris Langdon
Rosenstiel School of Marine and Atmospheric Science
Uni. of Miami
305-421-4614

Introduction

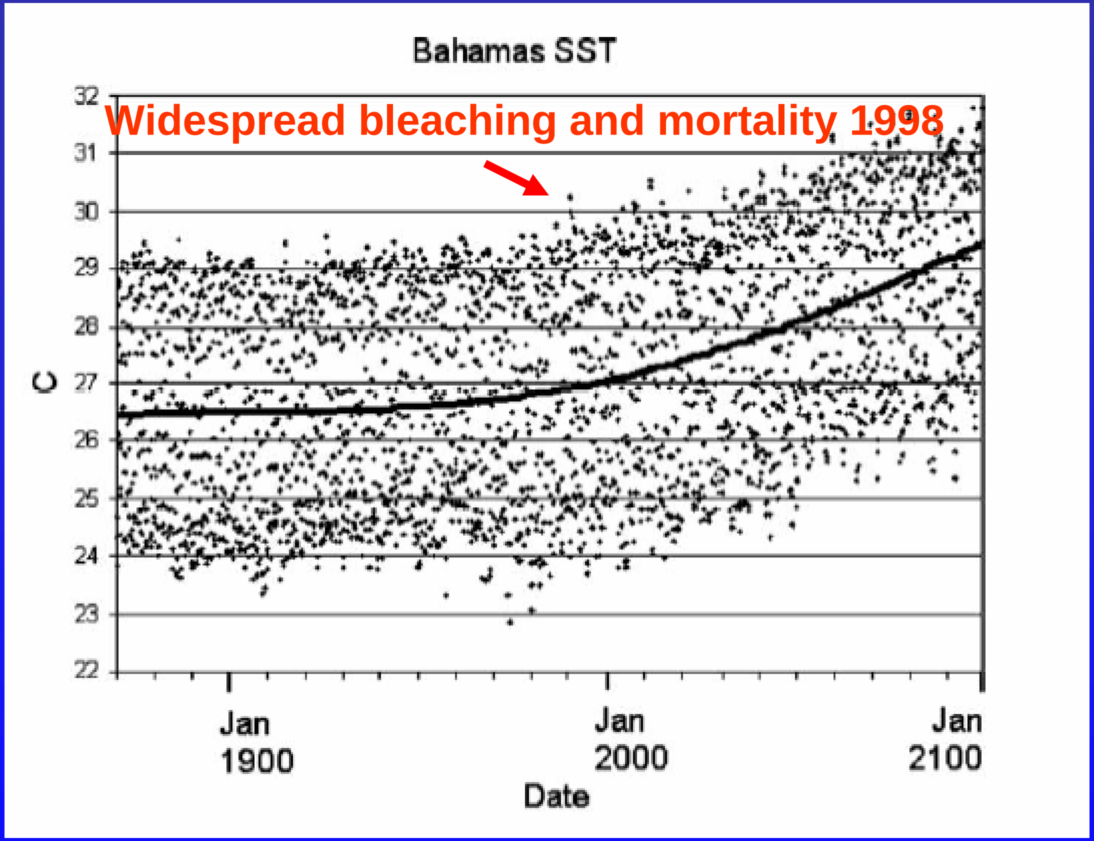
- The temperature and carbonate chemistry of reef waters have changed in the last 200 years.
  - 0.6°C warmer and 0.1 pH units more acidic
- Projections for the next 100 years predict much larger changes
  - Warming by 2-5°C and pH decline of 0.2-0.4 units

- These changes are larger than reefs have experienced over the last 400,000 years, possibly over the last 25 million years.
- More importantly, the rate of change of seawater carbonate chemistry is ~100-times faster than coral reef organisms have experienced in the past.
- Coral reefs are clearly showing signs of decline world wide over the last 20-30 years. It is unclear how much of this decline can be laid to global change and how big a threat the projected changes pose.

Threat posed by global warming

Historical temperatures (1871-1999) blended with model temperatures (1950-2099) assuming "business-as-usual" increase in CO_2

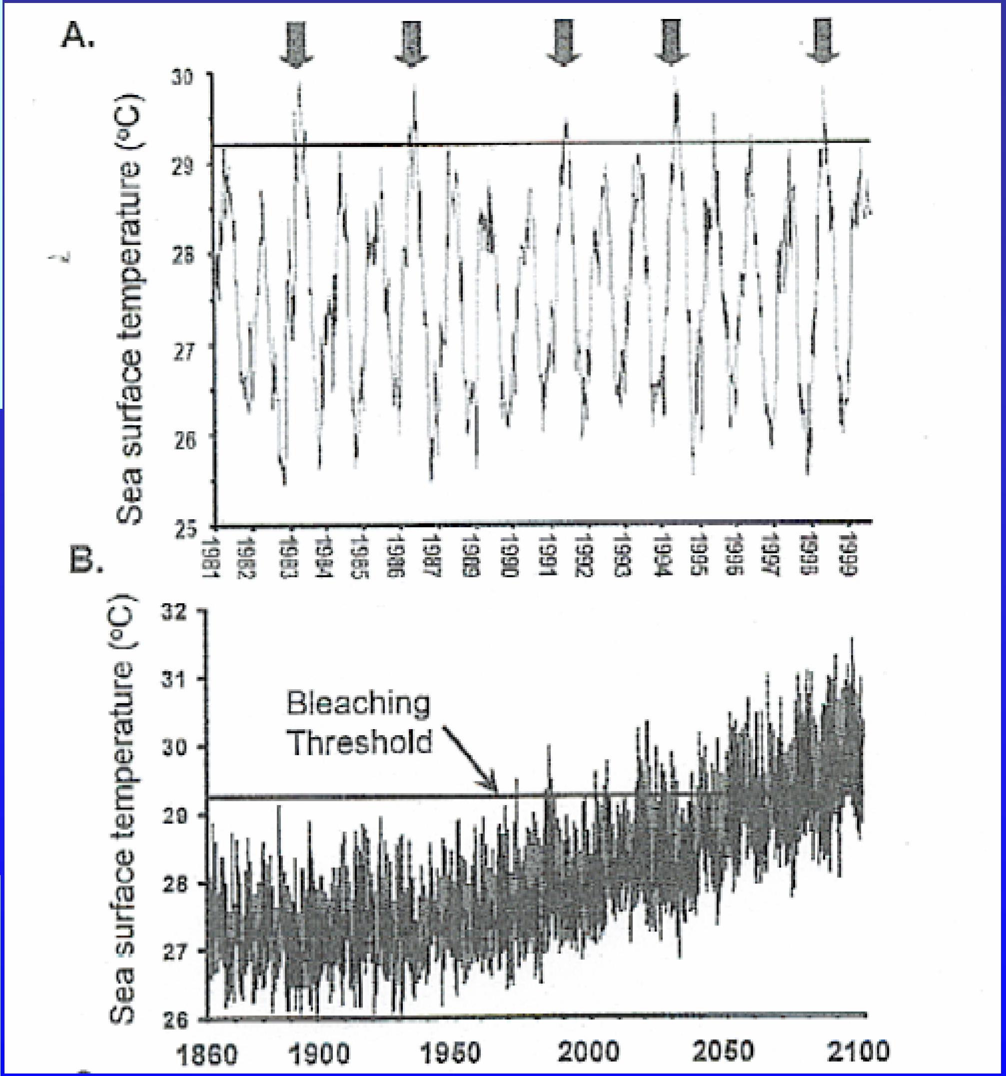
The SST increase of 0.5°C from 1900 to 1999 probably isn't responsible for much of the decline in coral reefs. However, the projected increase of 2.5°C over the next 100 years could have a large impact on the survival of coral communities and their ability to recover.



Sheppard and Rioja-Nieto 2005

Bleaching is where a coral loses its algal symbionts which supply 60-90% of the coral's energy. The typical cause is thermal stress but other factors (high visible or UV radiation, low salinity, aerial exposure, sedimentation and pollutants) are also important.

Bleaching events reported for coral reefs in Moorea, French Polynesia

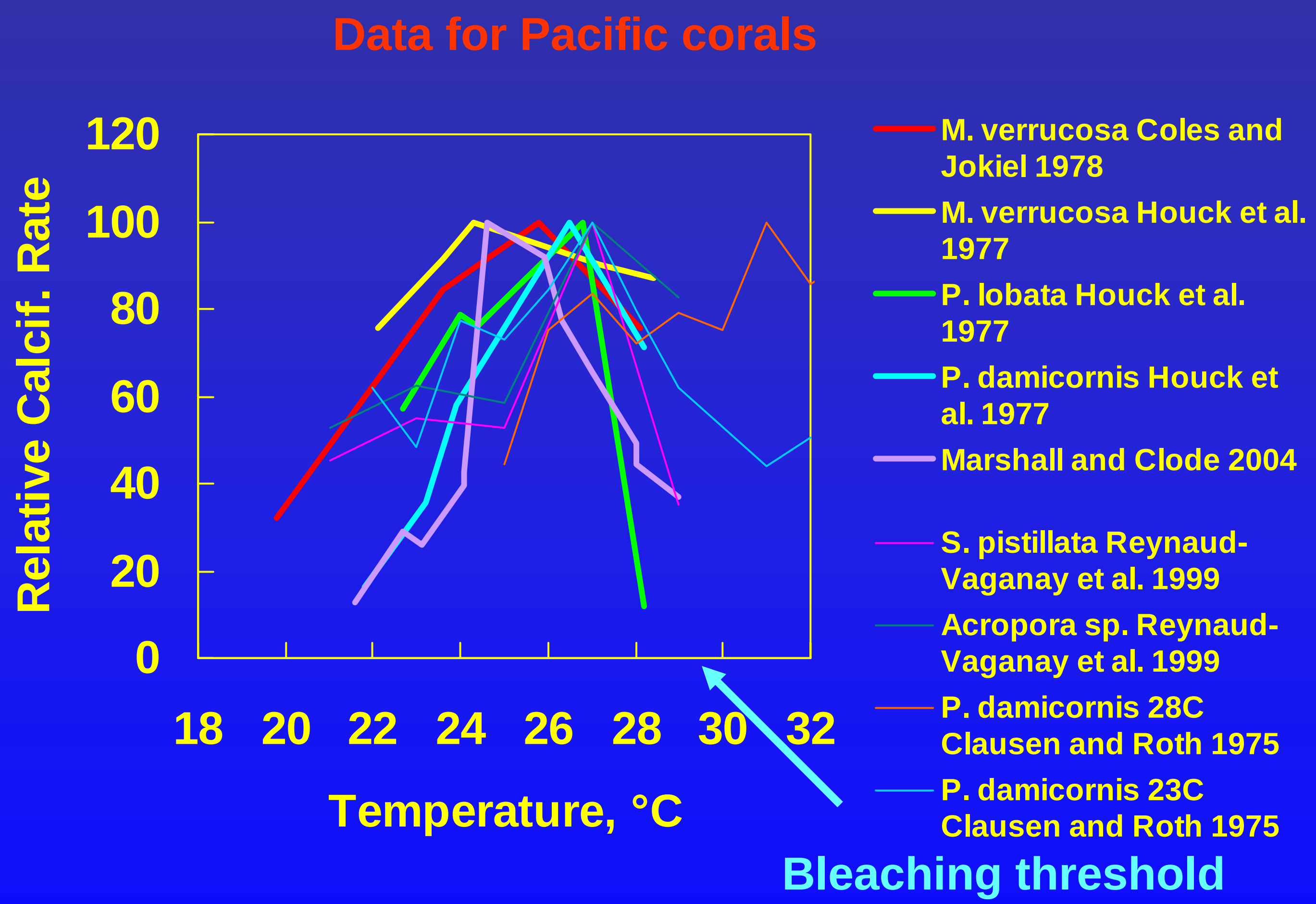


Corals bleach when temperatures exceed the normal summer average by more than 1°C for a month or longer. Recovery is is highly variable.

Global warming may cause an increased frequency of bleaching events but this has not yet been proven.

Hoegh-Guldberg 2005

Temperature dependence of coral calcification



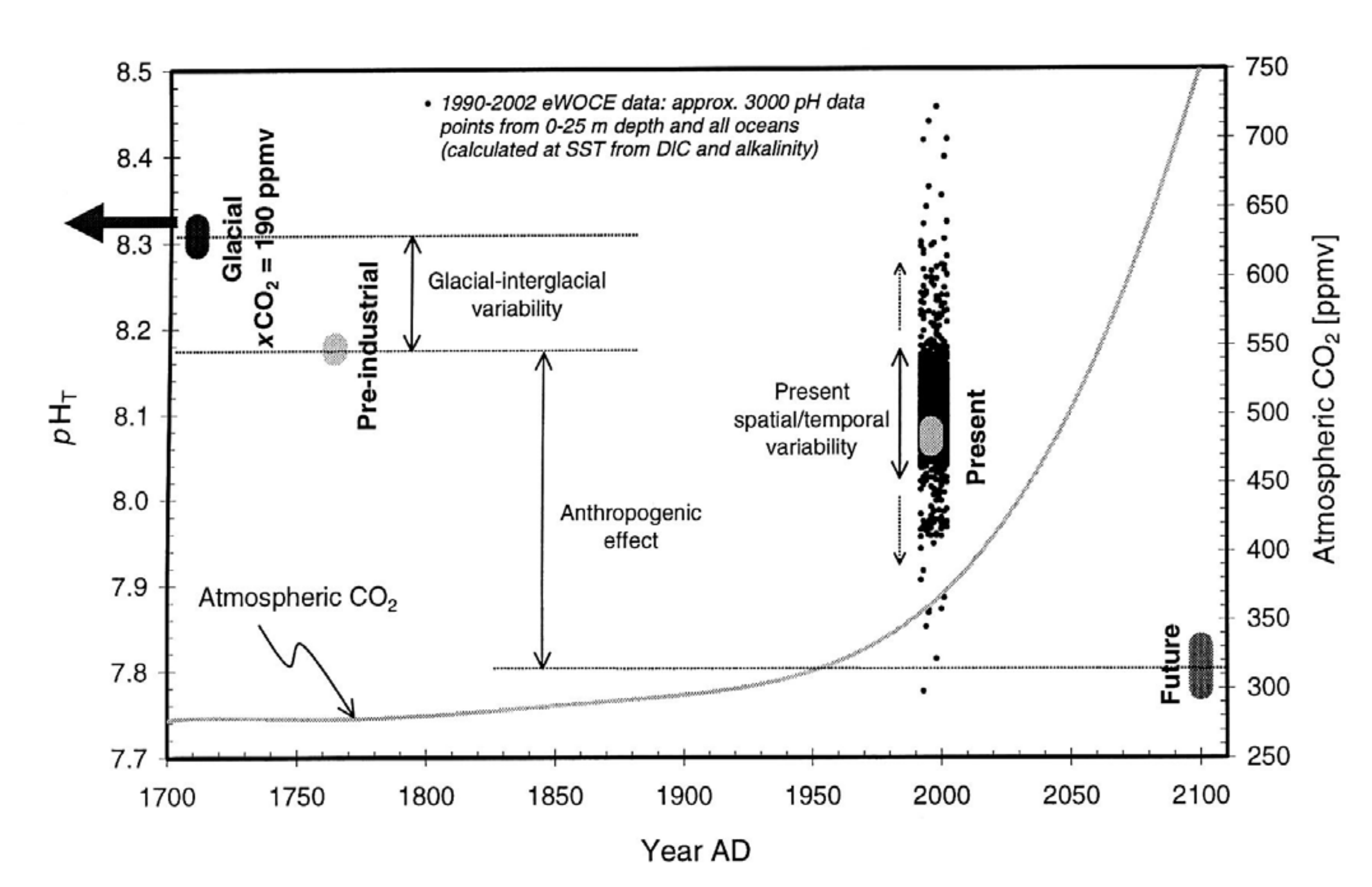
Optimum temperature for calcification is at or below ambient peak summer temperatures for many species.

Evaluating threat posed by warming

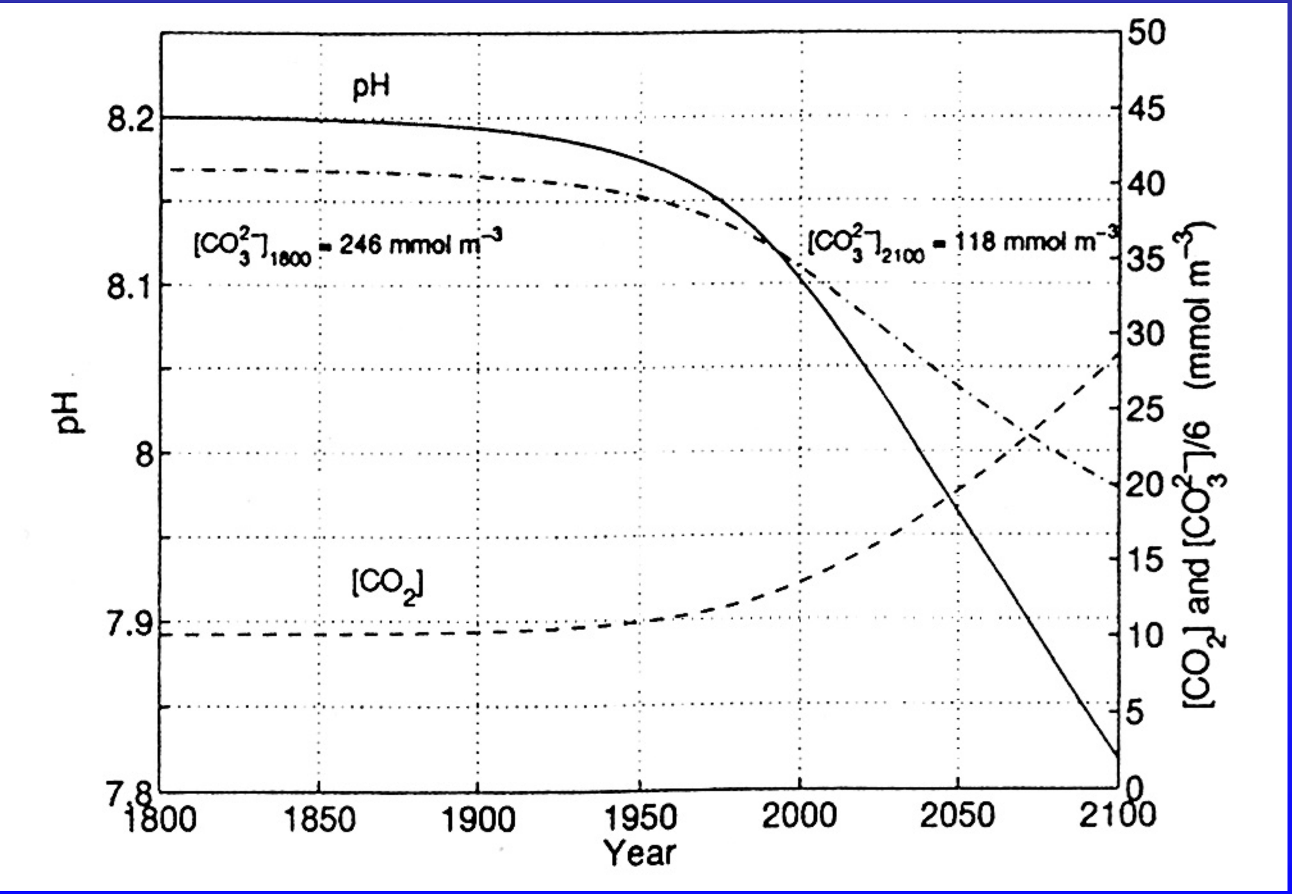
- Many corals seem to be thermally stressed by present day summer temperatures. Any warming is going to result in slower growth over the warm months and decreased annual growth if temperatures exceed thermal thresholds for a month or more mass mortality can occur.
- Some species seem to have the ability to adapt/acclimate to warmer conditions. It is unknown how quickly this adaptation/acclimation can occur and how prevalent this capability is across the different coral genera.

Threat posed by ocean acidification

On short time scales atmospheric CO_2 controls ocean pH



Projected changes in seawater carbonate chemistry



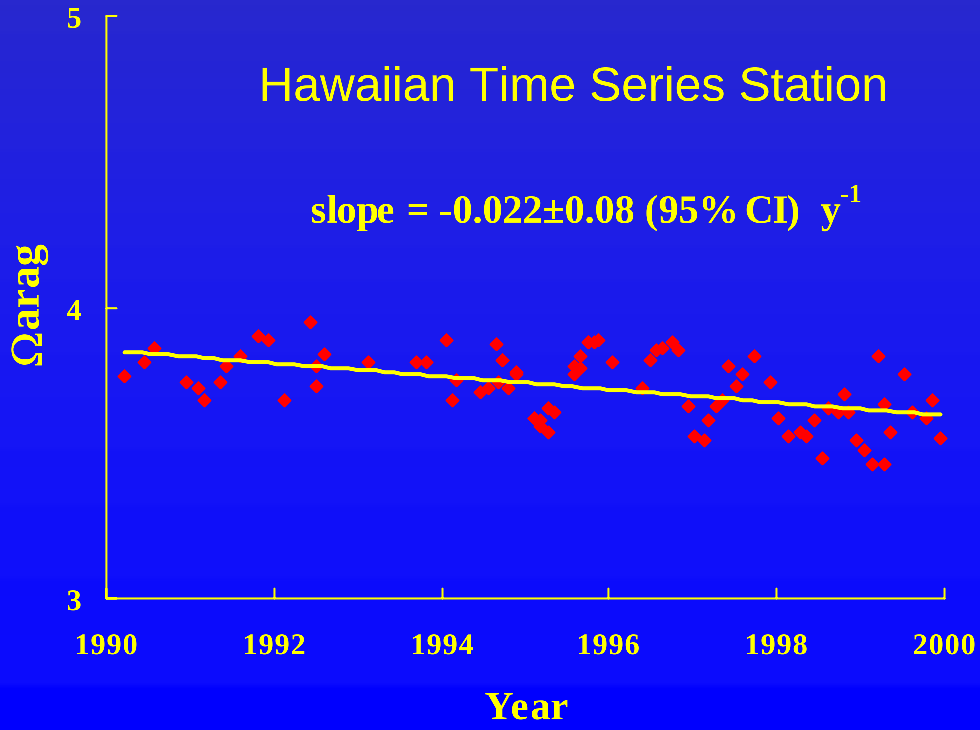
Wolf-Gladrow et al., 1999

Falling $[CO_3^{2-}]$ means that saturation state also falls

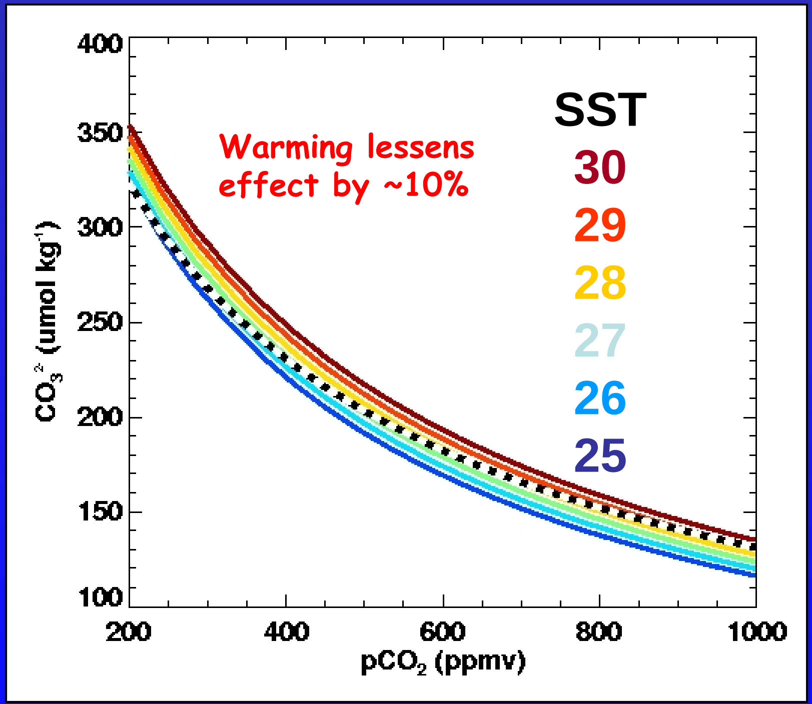
$\Omega_{arag} = [Ca^{2+}][CO_3^{2-}]/Ksp$

Ω_{arag} >1 promotes precipitation

Ω_{arag}<1 promotes dissolution



Projection for tropics



Kleypas et al., 1999

Royal Society Report on Ocean Acidification (June 2005)

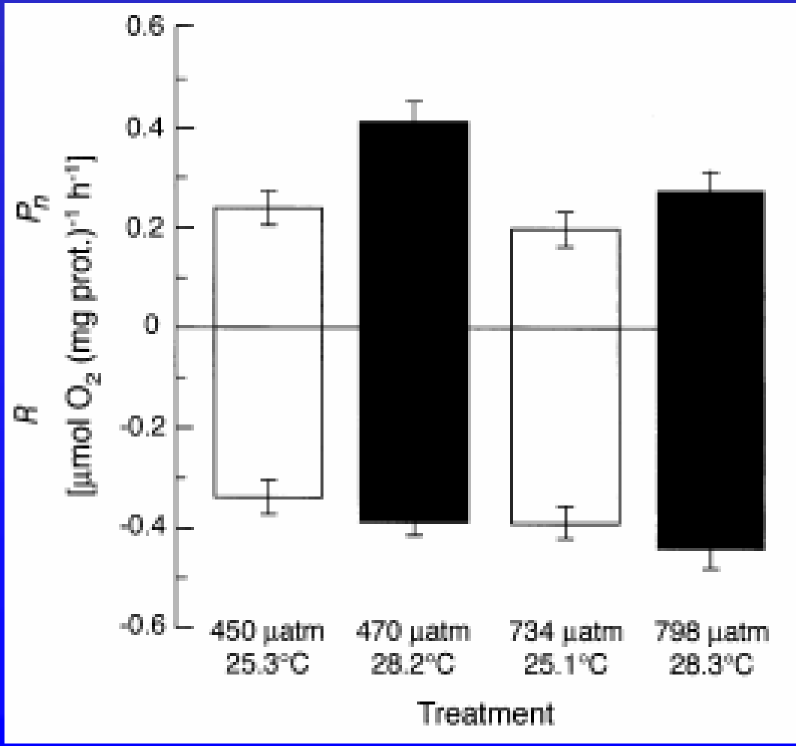
- The changes that have occurred are irreversible in our lifetimes.
- Reducing emissions of CO_2 to the atmosphere appears to be the only practical way to minimize the risk of large-scale and long-term changes to the oceans.
- Impacts will be greater for some regions and ecosystems, and will be most severe for coral reefs and the Southern Ocean.

How will the changes in seawater chemistry associated with the uptake of CO_2 released by the burning of fossil fuels impacts coral reefs?

- Will the 2-3-fold increase in $[CO_2]$ and 7-15% increase in $[HCO_3^-]$ stimulate the photosynthesis of the algal symbionts and will this in turn stimulate the calcification of the coral polyps?
- Will the 30-50% decline in $[CO_3^{2-}]$ and saturation state (Ω_a) have a direct effect on calcification?

Experimental studies of the effect of elevated pCO_2 on coral photosynthesis and respiration

Reynaud et al. 2003 looked at the effects of temperature and CO_2 on the photosynthesis, respiration and calcification of the coral *Stylophora pistillata.* Corals were grown for 5 weeks at each condition.



- Elevated pCO_2 caused slight reduction in net photosynthesis.
- Net photosynthesis increased with temperature as expected for this species.
- Cell specific density was 24% higher at elevated pCO_2 suggesting some disruption in the balance of growth rates of the algal and animal cells.
- Dark respiration not effected by elevated pCO_2 or temperature.

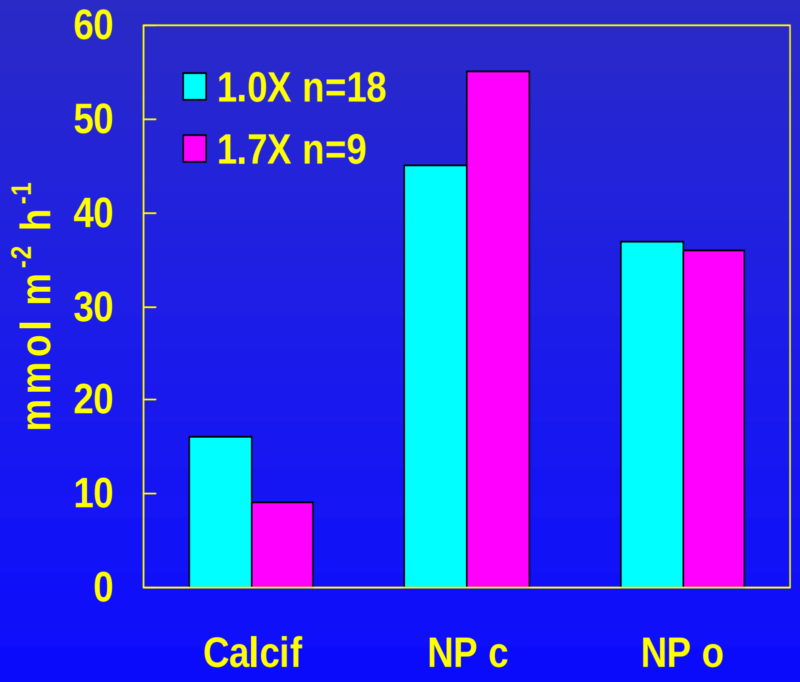
Experiment in an outdoor flowing seawater flume

- 200 closely packed colonies of corals forming a patch 2.2 m^2 in area simulating a patch of reef with 100% coral cover.
- Flowing seawater duplicates turbulent boundary conditions in the field.
- Receiving full natural sunlight
- Carbonate chemistry manipulated by addition of HCl or NaOH.

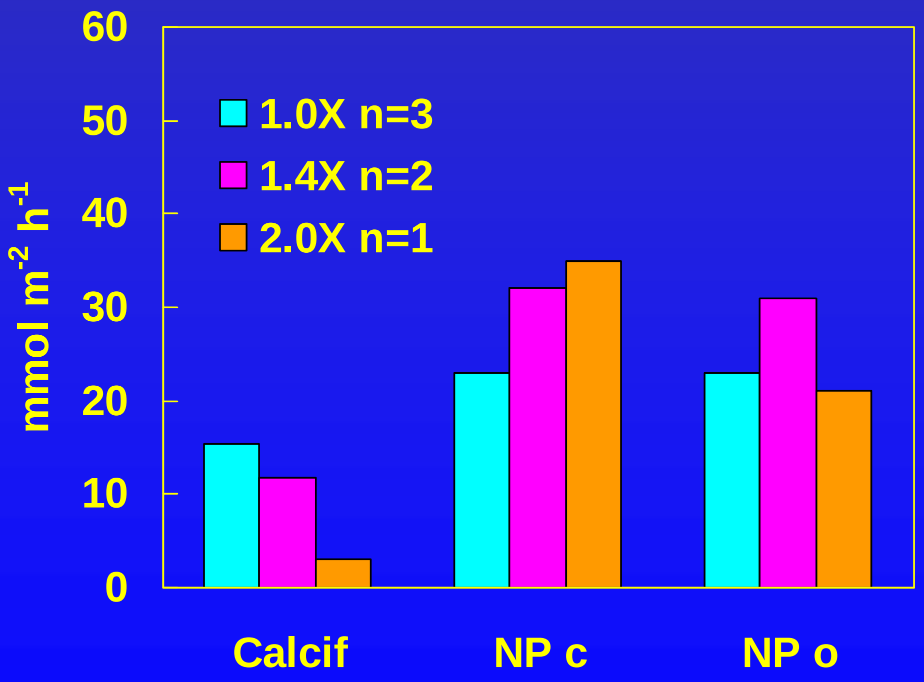
Langdon, C., and M.J. Atkinson, Effect of elevated pCO_2 on photosynthesis and calcification of corals and interactions with seasonal change in temperature/irradiance and nutrient enrichment, *J. Geophysical Res.*, in press.

Results of Flume experiment with *Porites compressa* and *Montipora capitata*

August 1999
27.3°C 37 E m^{-2} d^{-1}

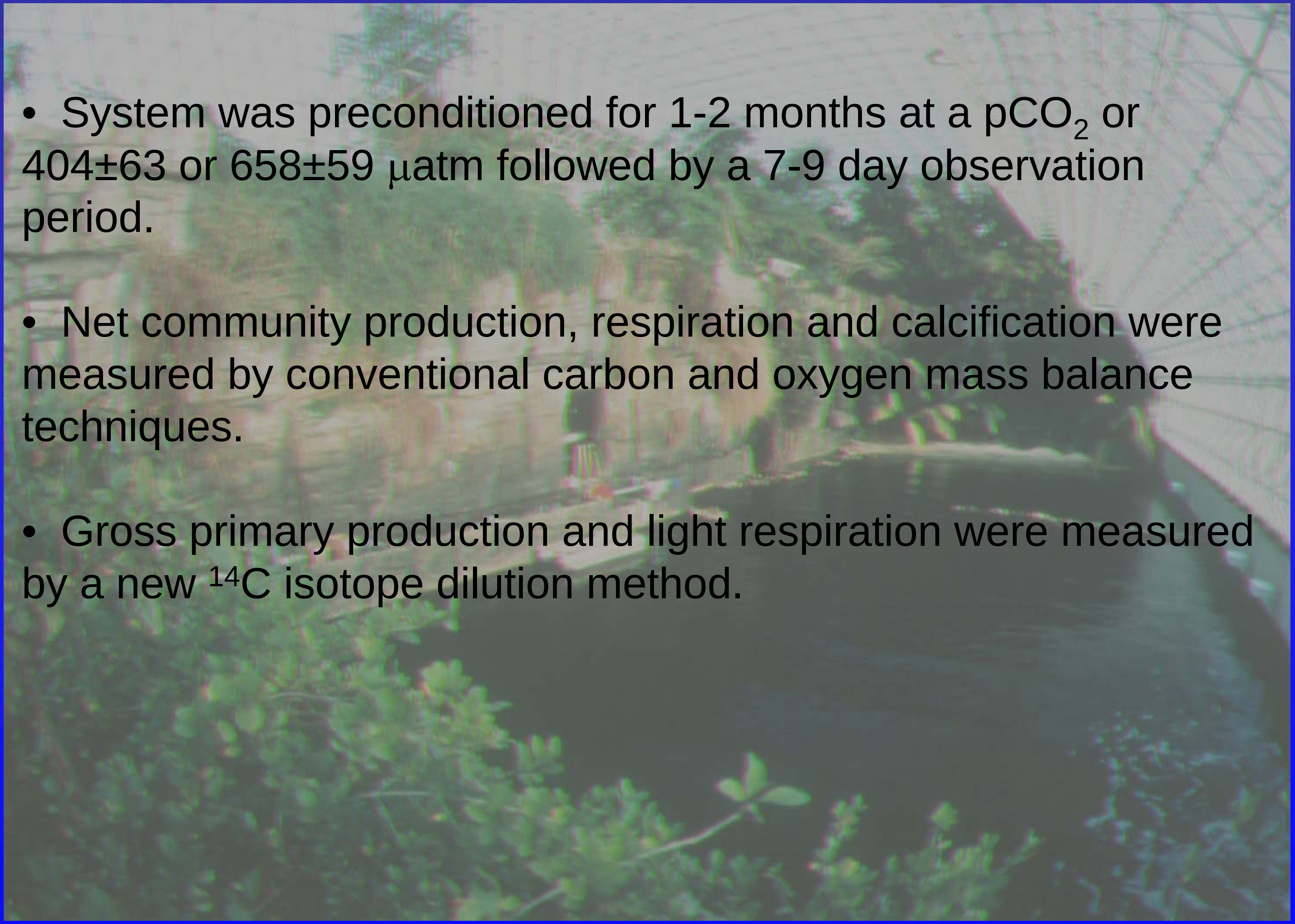


January 2000
23.4°C 19 E m^{-2} d^{-1}



Langdon and Atkinson, in press

Biosphere 2 coral reef experiment



- System was preconditioned for 1-2 months at a pCO_2 or 404±63 or 658±59 μatm followed by a 7-9 day observation period.
- Net community production, respiration and calcification were measured by conventional carbon and oxygen mass balance techniques.
- Gross primary production and light respiration were measured by a new ^{14}C isotope dilution method.

Results of B2 experiment

(Rates in mmol C m^{-2} d^{-1})

pCO_2, μatm	404	658
NCP_C	-0.01±0.01	-0.001±0.005
R_{dark}	**0.115±0.003**	**0.104±0.005**
R_{light}	**0.14±0.03**	**0.22±0.04**
GPP	**0.24±0.03**	**0.32±0.04**
Calcification	**0.041±0.007**	**0.006±0.003**

Significant changes in bold

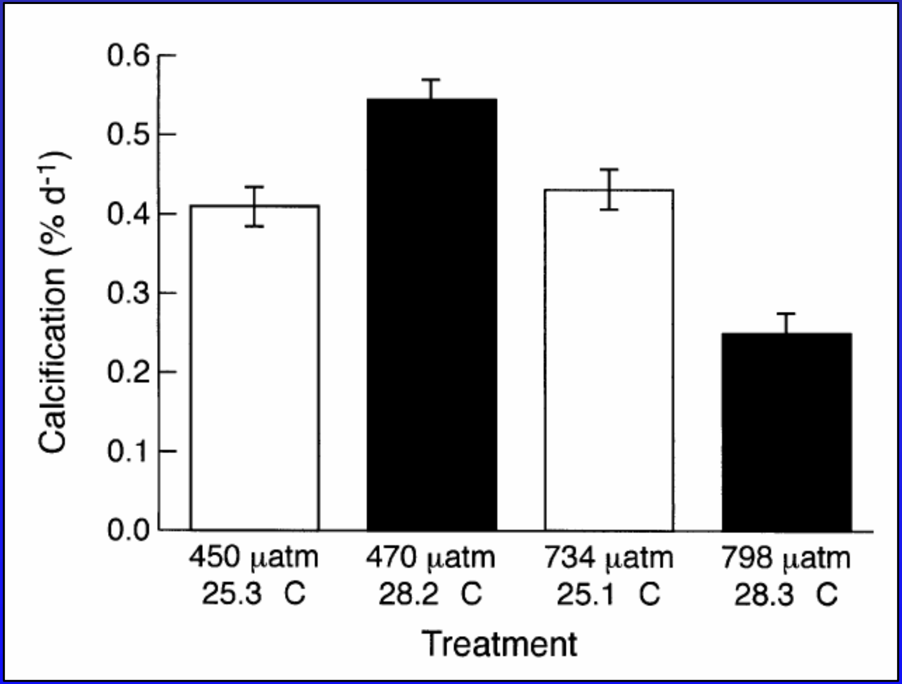
Langdon et al. (2003) Effect of elevated CO2 on the community metabolism of an experimental coral reef. Global. Biogeochemical Cycles 17(1): Art. No. 1011.

Synthesis of effects of elevated CO_2 on cycling of organic carbon

- In two of three studies doubling in pCO_2 had no significant effect on NCP and dark respiration. In third study it had a significant positive effect on NCP_C but not NCP_O.
- ^{14}C isotope dilution study showed that doubling in pCO_2 may enhance the rate of cycling of organic carbon but had no impact on net production or respiration.

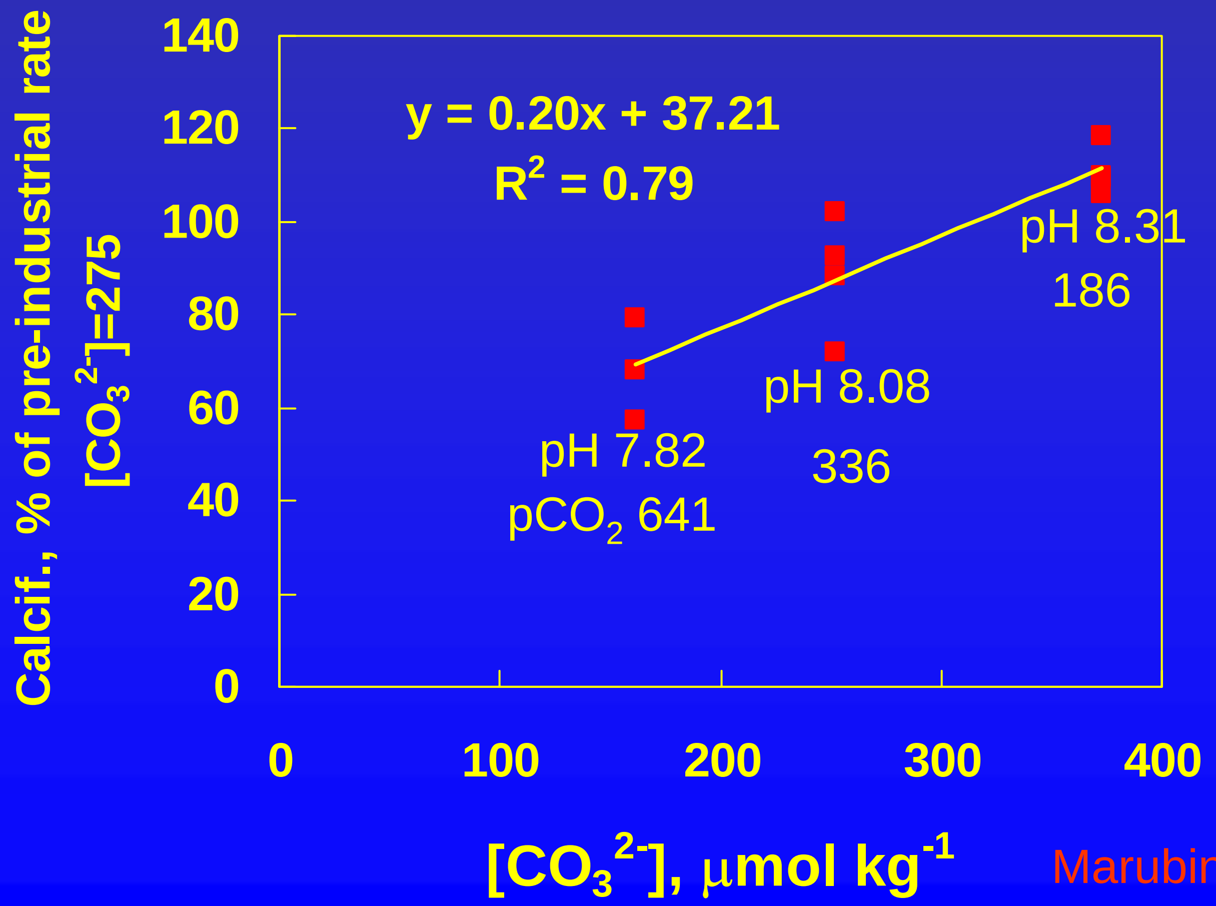
Experimental studies of the effect of elevated pCO_2 on coral calcification and skeletal growth

Interesting interactions of temperature and CO_2 on coral calcification



- Elevated pCO_2 caused no significant change in calcification at 25°C but a 50% reduction at 28°C.
- The reduction in calcification was immediate and persisted unchanged over the 5 wk experiment.
- At normal pCO_2, the increase in temperature caused an increase in calcification but at elevated pCO_2 the increase in temperature caused a 34% reduction in calcification.
- One interpretation is that elevated pCO_2 reduced the thermal optimum for this species.

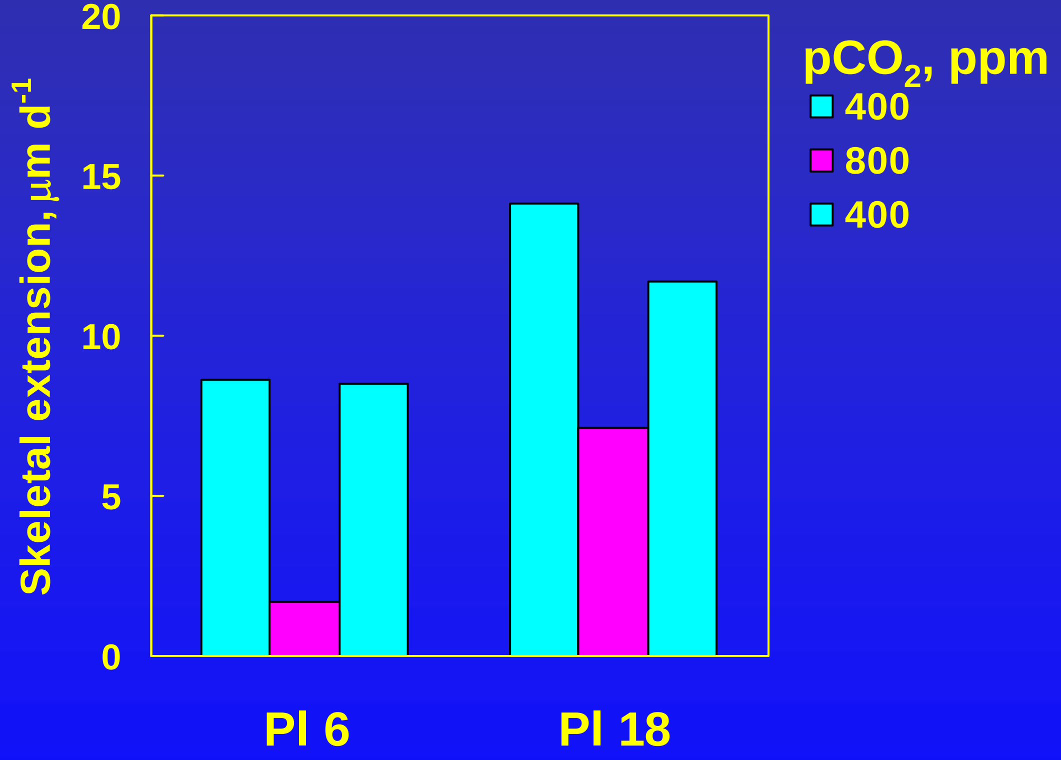
Response of nubbins of *Porites compressa* grown in the Biosphere 2 mesocosm for six weeks at four different depths and three different carbonate concentrations



Marubini et al. 2001

Effect of pCO_2 on vertical extension of *Porites lobata*

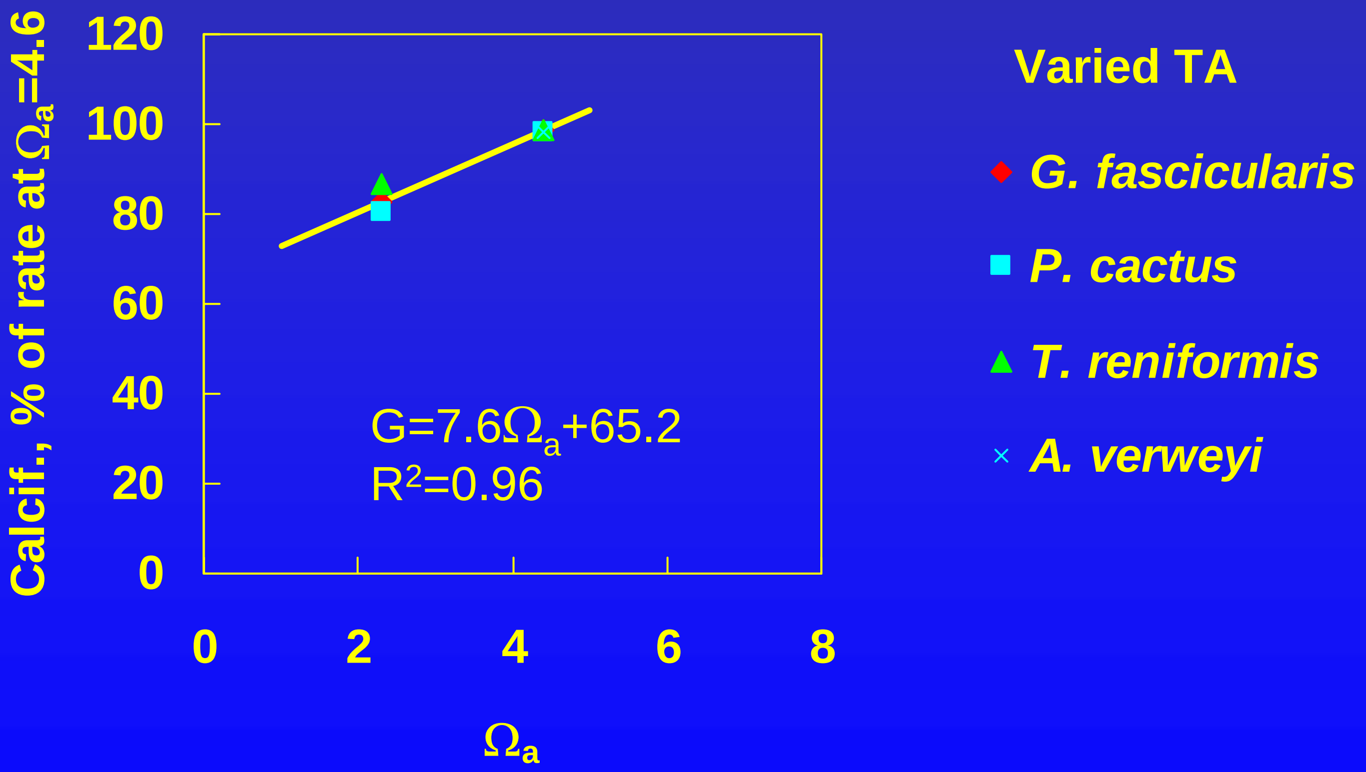
Data collected using optical micrometer



Elevated pCO_2 causes an immediate but reversible 45-80% reduction in skeletal extension

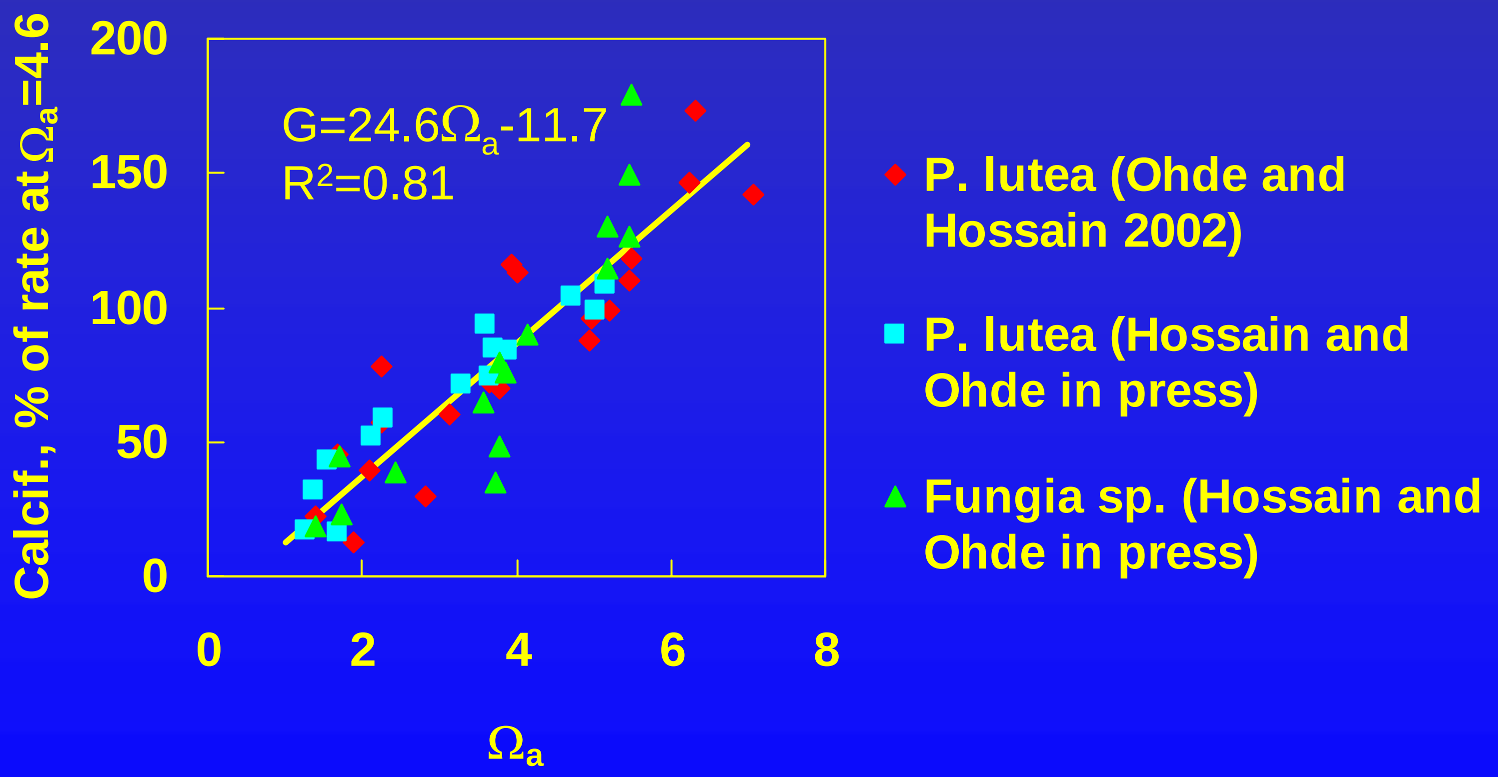
Langdon in prep.

Indo-Pacific corals of branching and foliose structure

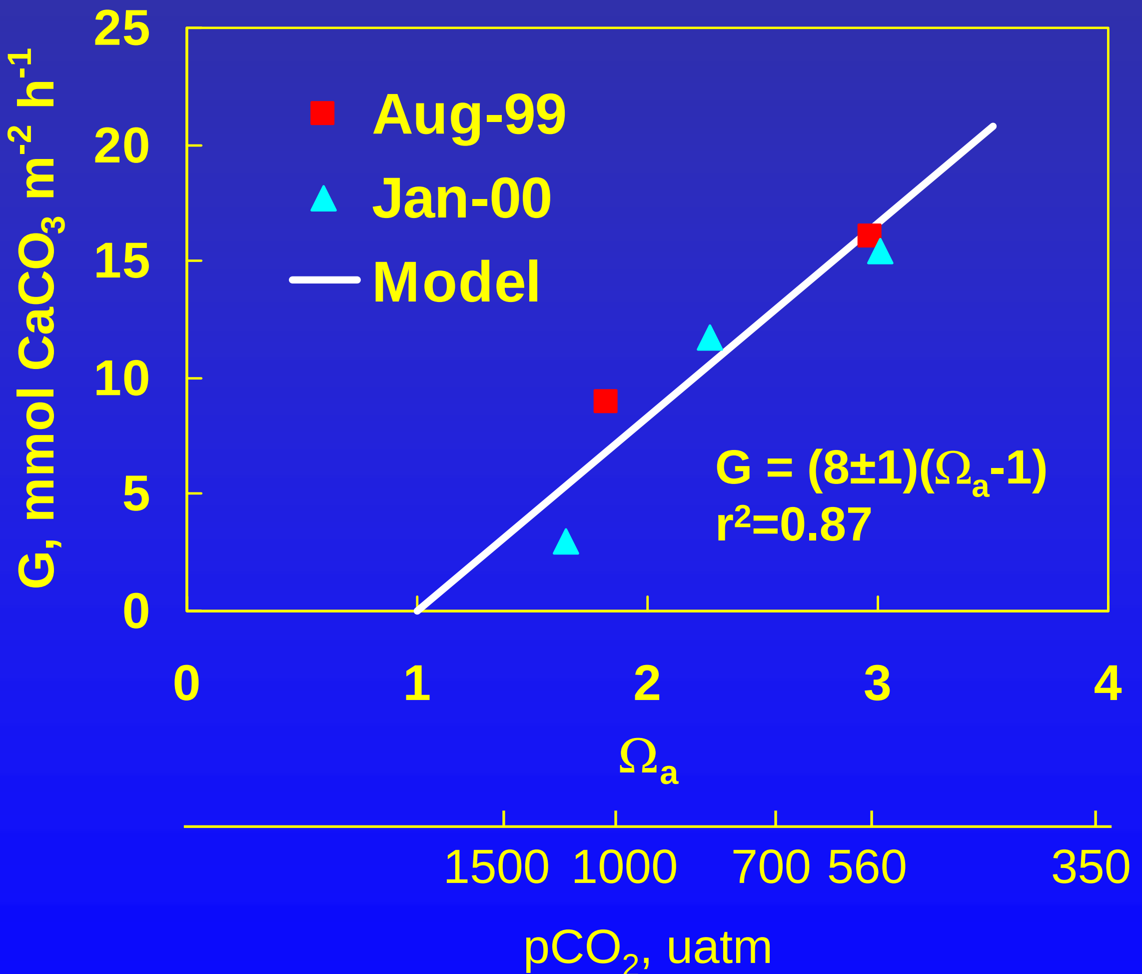


Marubini et al. 2002

Pacific massive coral *Porites lutea and Pacific solitary coral Fungia sp.*



Kaneohe Bay flume experiment



Langdon and Atkinson, in press

Effect of a doubling in pCO_2 on calcification

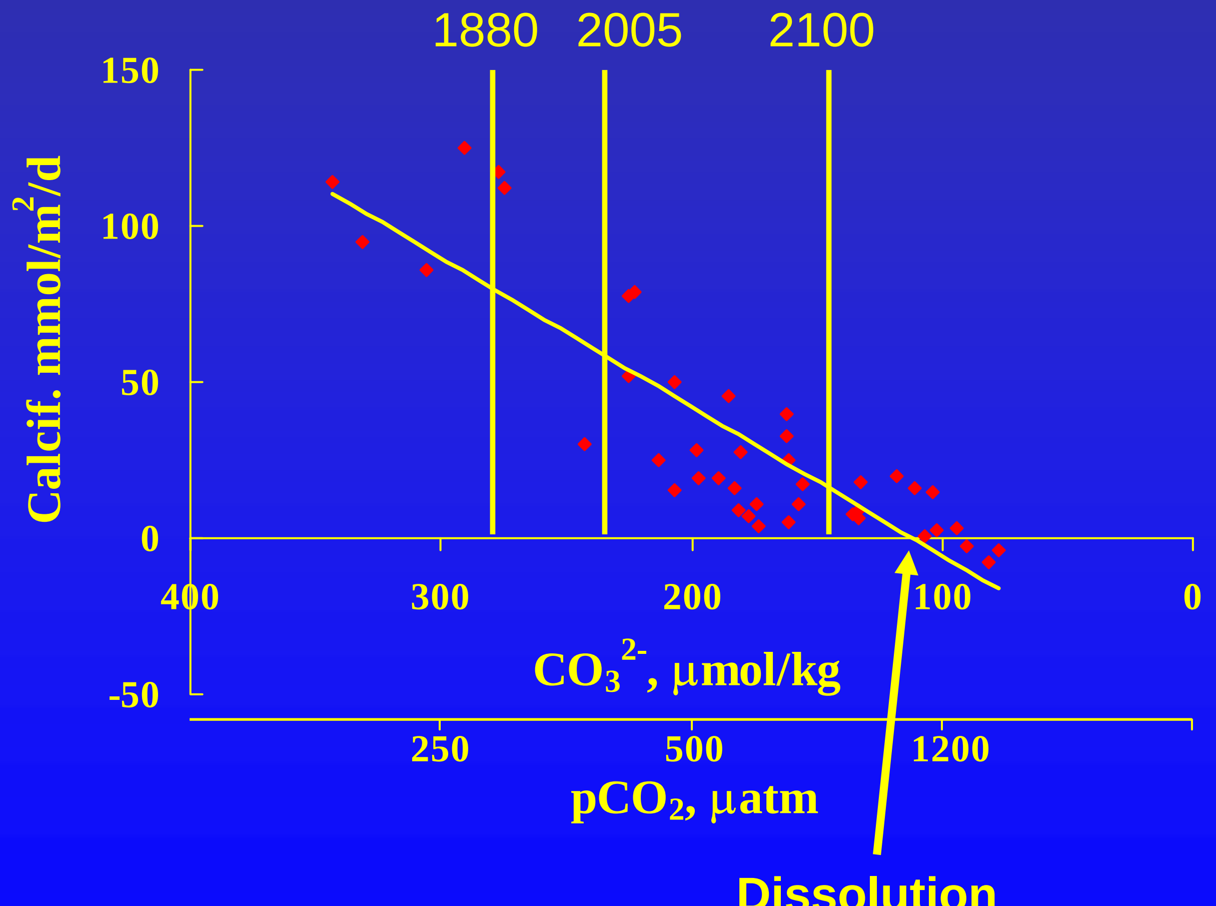
Wide range of sensitivity

Species	Source	% decline by 2065
S. pistillata	**Gattuso et al. 1998**	**-3**
P. compressa	**Marubini et al. 2001**	**-16**
G. fascicularis	**Marubini et al. 2002**	**-11**
P. cactus	**“ “**	**-13**
T. reniformis	**“ “**	**-9**
A. verweyi	**“ “**	**-13**
S. pistillata (25C)	**Reynaud et al. 2003**	**+7**
“ “ (28C)	**“ “**	**-57**
P. lutea	**Ohde and Hossain 2004**	**-38**
P. compressa/M. capitata	**Langdon and Atkinson in press**	**-41**
P. lutea	**Hossain and Ohde, in press**	**-33**
Fungia sp.	**“ “**	**-60**

-8%

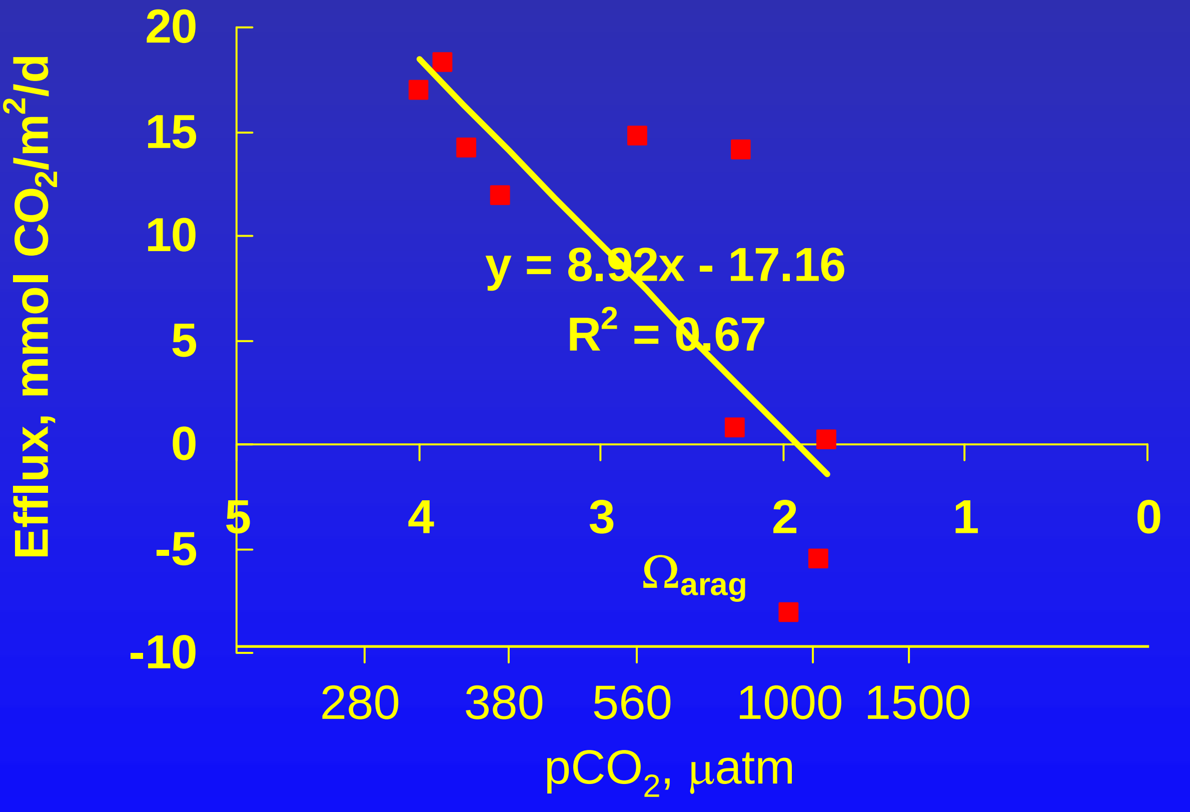
-46%

Response of Biosphere 2 coral reef mesocosm to altered $[CO_3^{2-}]$



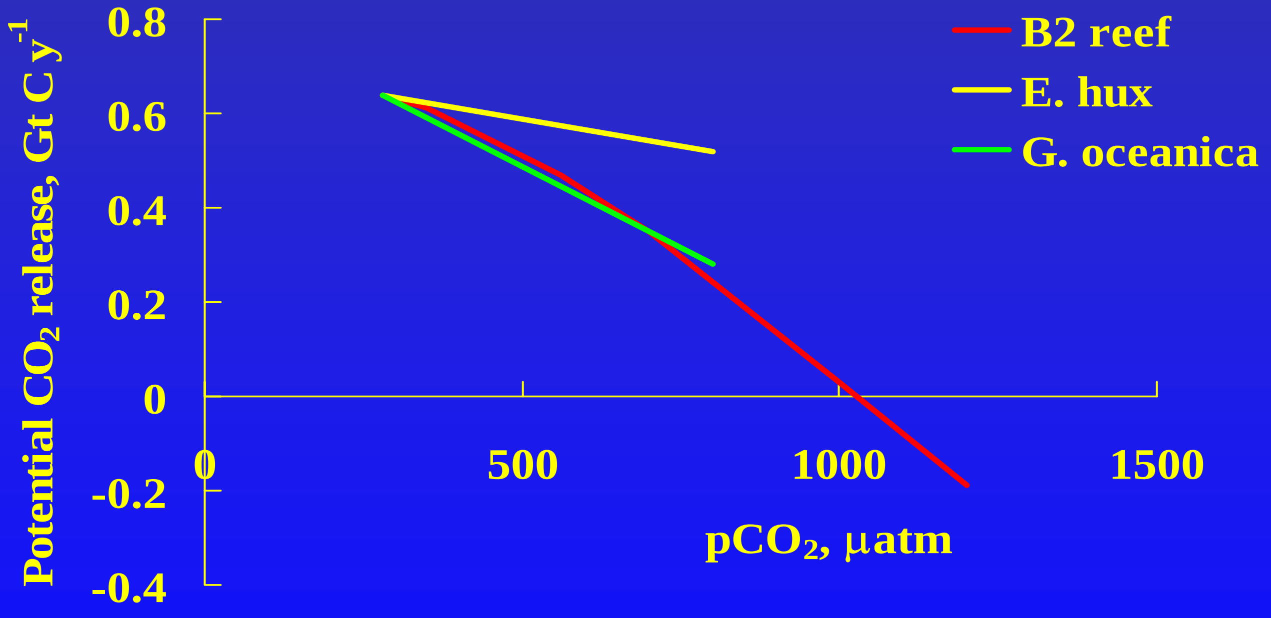
Langdon et al. 2000

Air-sea flux of CO_2 from Biosphere 2 mesocosm reflects changes in calcification rate of underlying community



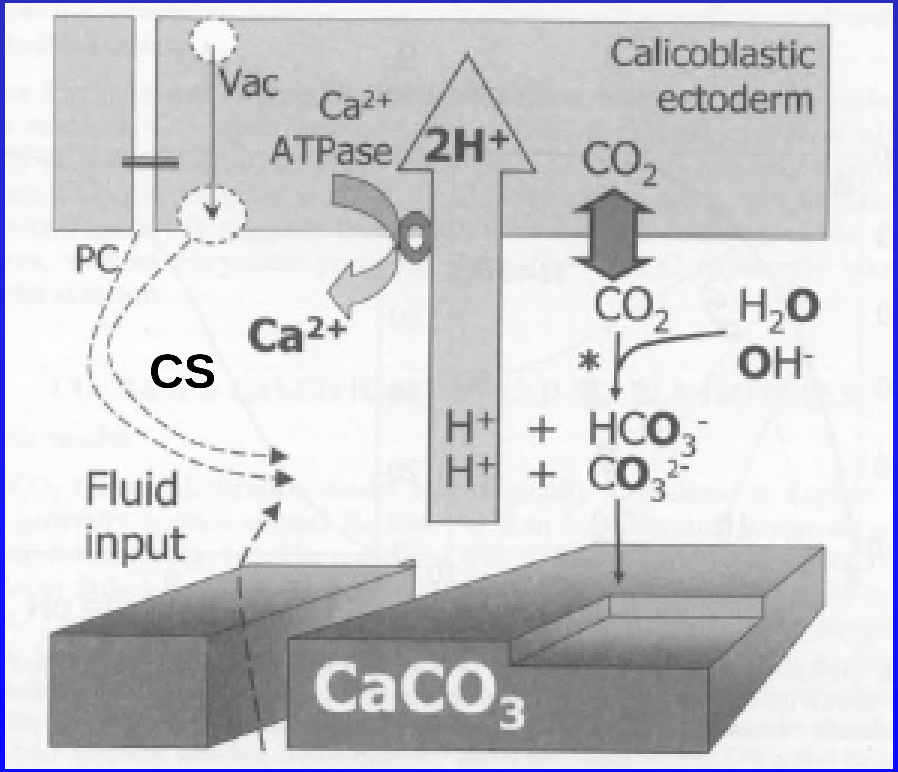
Unpublished data from Biosphere 2 experiment

Scaling up from experimental results the global flux of CO_2 from sea to atmosphere due to biogenic calcification could decline by 0.2-0.6 Pg C y^{-1}



Zondervan et al. (2001) with B2 data overlain

Physiological model for coral calcification



Cohen and McConnaughey 2003

Seawater reaches the calcifying space via diffusion thru porous skeleton, junctions between cells or exocytosis of vacuoles.

Light-activated Ca-ATPase pumps Ca^{2+} into the calcifying space (CS) during the day. However, its main role is to transport H^+ out of the CS thereby maintaining a pH favorable to the conversion of CO_2 to CO_3^{2-}.

This scheme does not explain how a change in external [CO_3^{2-}] would effect the pH in the CS.

Findings

- No significant impact on net production or respiration.
- Effect of saturation state on calcification did not exhibit a threshold response, any decrease was detrimental to coral calcification and growth.
- A saturation state of <1.0 is a clear crisis point below which some corals can not grow at all (pCO_2=1200 μatm), however, on a reef where there are organisms actively biting and boring the corals the point of zero net growth is probably reached at a much lower pCO_2 level.

Next steps

- Combination temperature and pCO_2 experiments.
- Longer experiments to see if corals can acclimate or adapt.
- Experiments to see how reproduction and success of early life stages will be effected.
- Need to start time series observations of carbonate chemistry, air-sea CO_2 flux and reef ecology at one or more coral reefs.
- Study coral reefs in the Galapagos that are exposed to high CO_2, upwelled water because they may be present day analogs of how reefs will look in the future, however, would have to sort out impacts of low temperature and high nutrients.