Global change in the ocean

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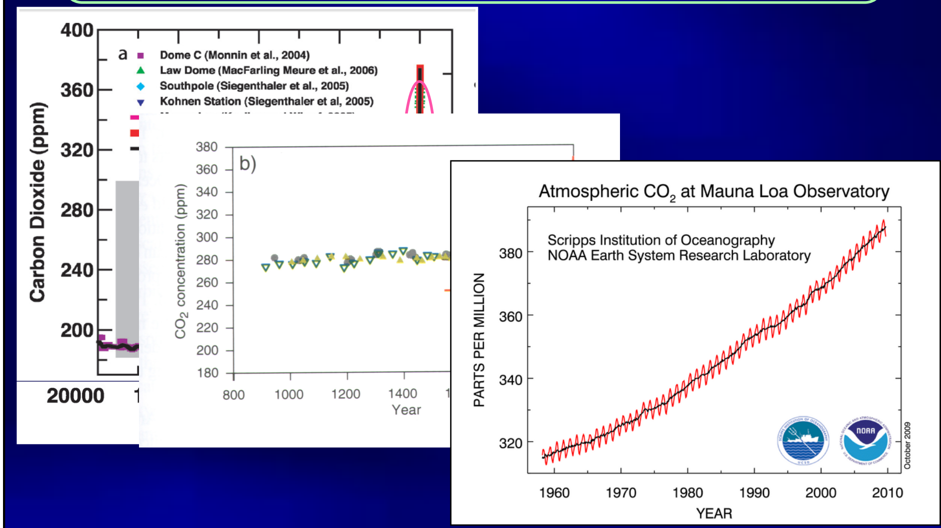
A few definitions

GLOBAL CHANGE: Changes in the Earth system (land, oceans, atmosphere, poles, life, the planet's natural cycles)

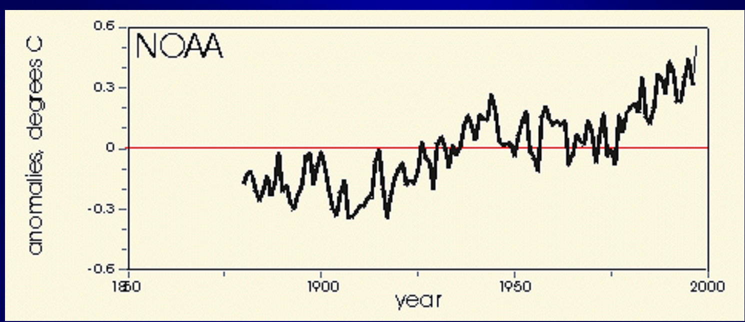
↳ GLOBAL WARMING: Increase in the Earth's temperature, with consequent CLIMATE CHANGE

↳ OCEAN ACIDIFICATION: Decrease of ocean pH and calcium carbonate saturation

Carbon dioxide increase in the atmosphere



Ocean warming



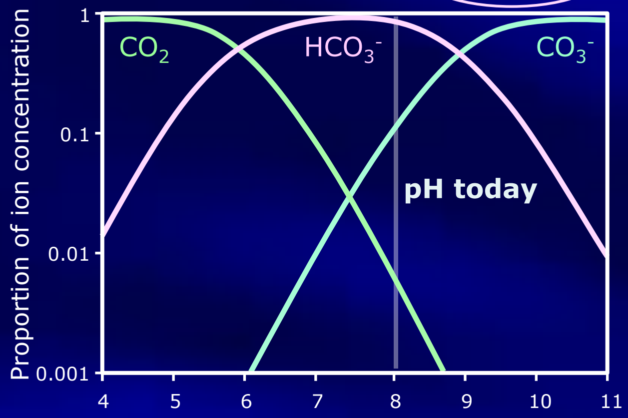
Global: Warming of superficial layer 0.5 - 1.5°C

Regionnally: 4 - 7°C (e.g. SE Australia)

Ocean acidification

- The oceans have absorbed ~1/3 of CO_2 emissions
- Affects the ocean chemistry, **carbonate system** and **pH**

$CO_2\ (aq) + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+ \leftrightarrow CO_3^{2-} + 2H^+$

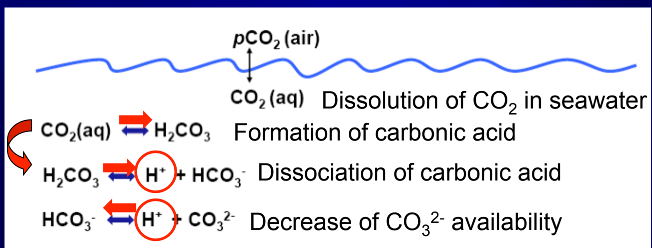


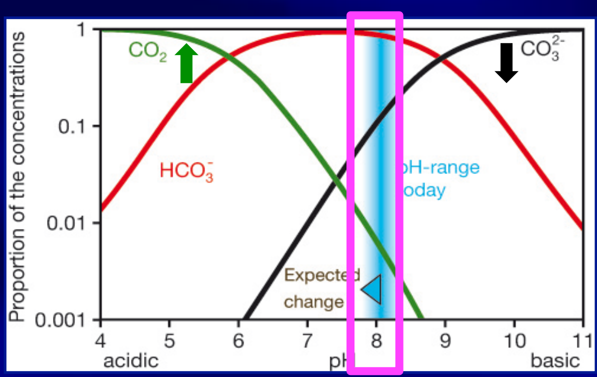
pH = - log [H^+]

0.1 pH units ↓
30% [H^+] ↑

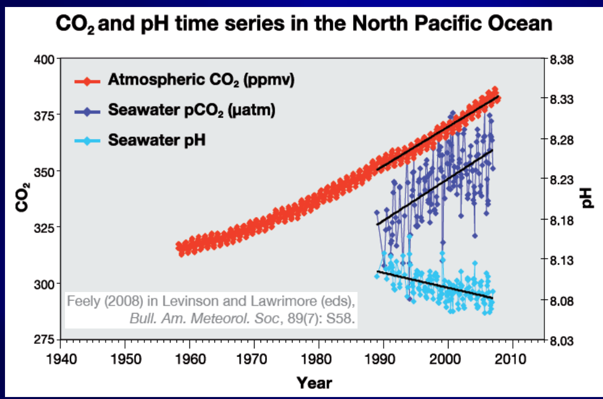
http://en.wikipedia.org/wiki/File:Carbonate_system_of_seawater.svg

Ocean acidification





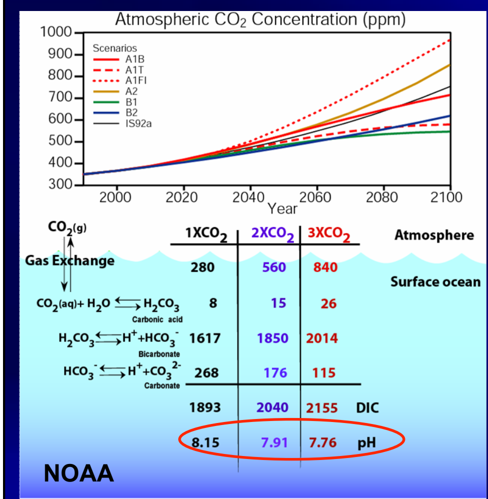
Ocean acidification is ongoing

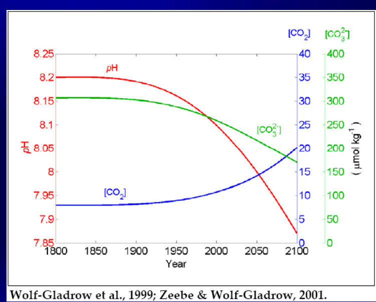


0.1 unit decrease since the Industrial Revolution

OA future predictions

By **2100** seawater pH will decrease around **0.3-0.5** units. By **2300** pH can decrease **0.77** units. (Caldeira & Wicket 2003, Caldeira & Wicket 2005, IPCC 2007)





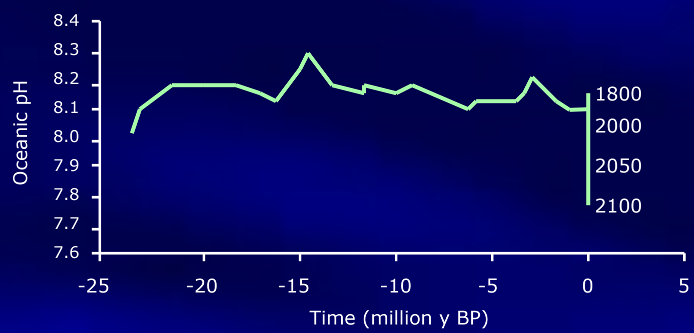
A1F1: high economic growth, fossil fuels

B1: alternative and renewable energies

A2: lower economic growth, some renewable energies

Ocean acidification predictions

OA is happening at a rate and to a level not experienced by marine organisms for ~ 20MY.



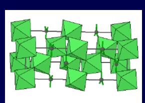
Pearson and Palmer (2000) and Turley et al. (2006) (Eur-Oceans Fact Sheet No. 7 2007)

SATURATION STATE OF CALCIUM CARBONATE ($CaCO_3$):

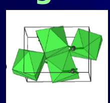
$$\Omega = \frac{[Ca^{2+}][CO_3^{2-}]}{K^*_{sp}} \quad (K^*_{sp\ cal} \neq K^*_{sp\ ar})$$

- $\Omega > 1$: precipitation
- $\Omega = 1$: equilibrium
- $\Omega < 1$: dissolution

Calcite

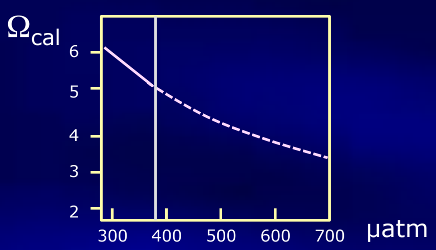


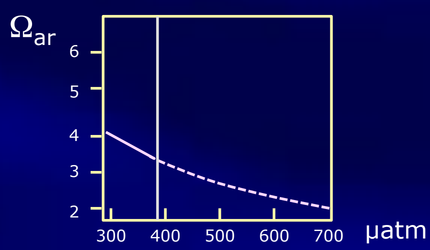
Aragonite



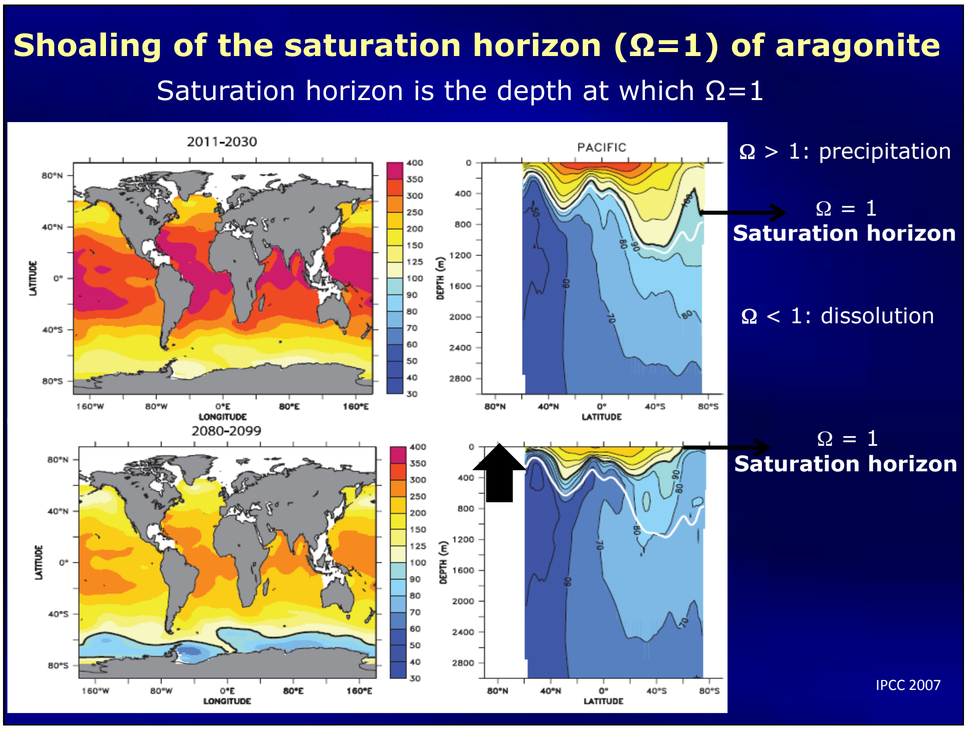
Aragonite is more soluble than Calcite: $\Omega_{ar} < \Omega_{cal}$

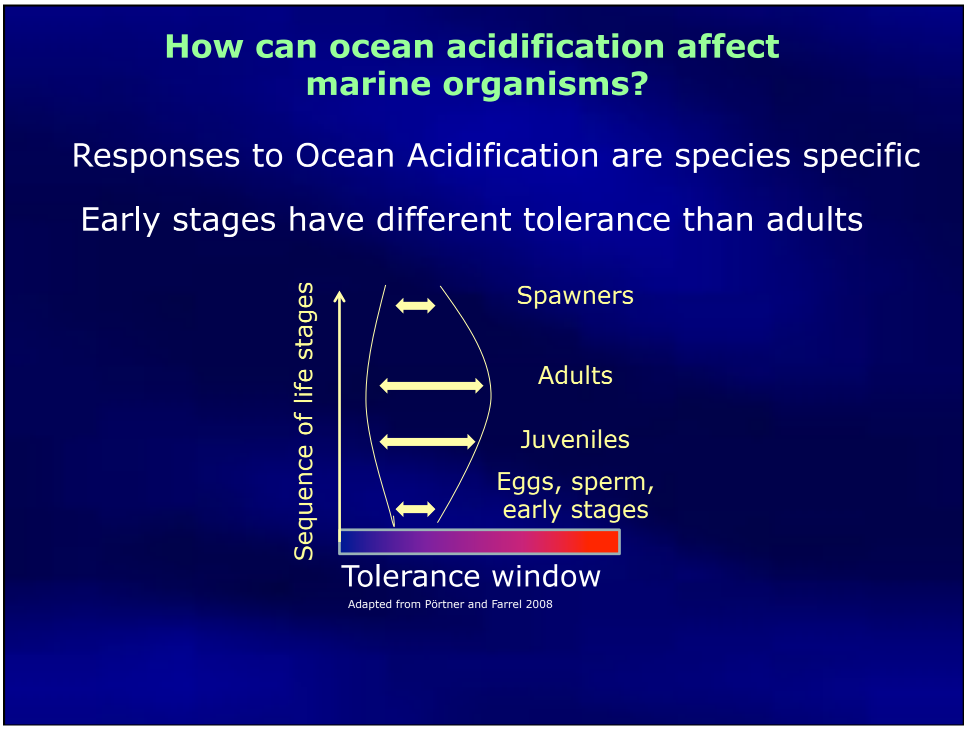
Saturation state evolution according to atmospheric pCO_2





Schulz 2008


Shoaling of the saturation horizon (Ω=1) of aragonite
Saturation horizon is the depth at which Ω=1
2011-2030
2080-2099
PACIFIC
LATITUDE
LONGITUDE
DEPTH (m)
Ω > 1: precipitation
Ω = 1
Saturation horizon
Ω < 1: dissolution
Ω = 1
Saturation horizon
IPCC 2007


How can ocean acidification affect marine organisms?
Responses to Ocean Acidification are species specific
Early stages have different tolerance than adults
Sequence of life stages
Spawners
Adults
Juveniles
Eggs, sperm, early stages
Tolerance window
Adapted from Pörtner and Farrel 2008

How can ocean acidification affect marine organisms?

Key physiological processes of an organism

Energy input	Energy maintenance	Energy output
Feeding ⟷	Metabolism ⟷	Growth
		Calcification
		Reproduction → Recruitment
	Survival (acclimatization)	

Acclimatization / Adaptation

Impact of OA on marine organisms

CALCIFICATION

The impacts of OA on calcifiers (**$CaCO_3$ skeleton**) was one of the first researchers concerns.

The main calcifiers in marine environments:

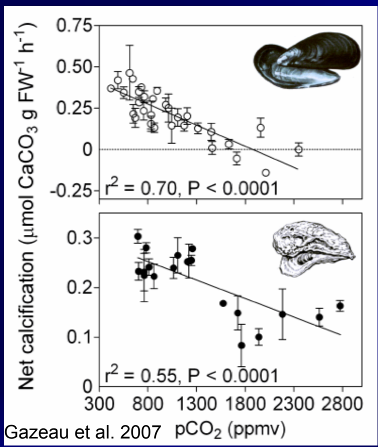
- Coccolithophoridae** (calcite)
- Foraminifera* (Mg-calcite: $MgCaCO_3$; aragonite)
- Corals (aragonite; calcite)
- Calcareous algae (aragonite; calcite)
- Pteropods* (aragonite)
- Other molluscs (calcite; aragonite), echinoderms (Mg-calcite), sponges (aragonite; calcite; Mg-calcite), arthropods (calcite; aragonite)

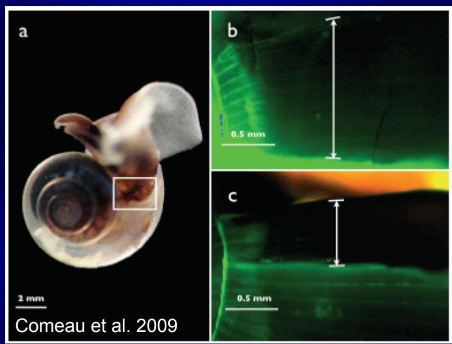
* Produce the most biogenic carbonate precipitated in the open oceans

Impact of OA: calcification

Laboratory studies:

Some species show a decrease of their calcification rates when exposed to lower pH seawaters (i.e. higher pCO_2 and lower $\Omega CaCO_3$).

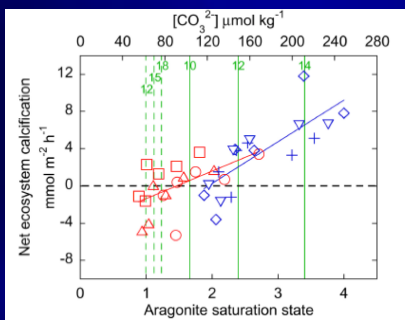




Decrease of calcification rates of *Mytilus edulis, Crassostrea gigas* and arctic pteropods under high pCO_2.

Impact of OA: calcification

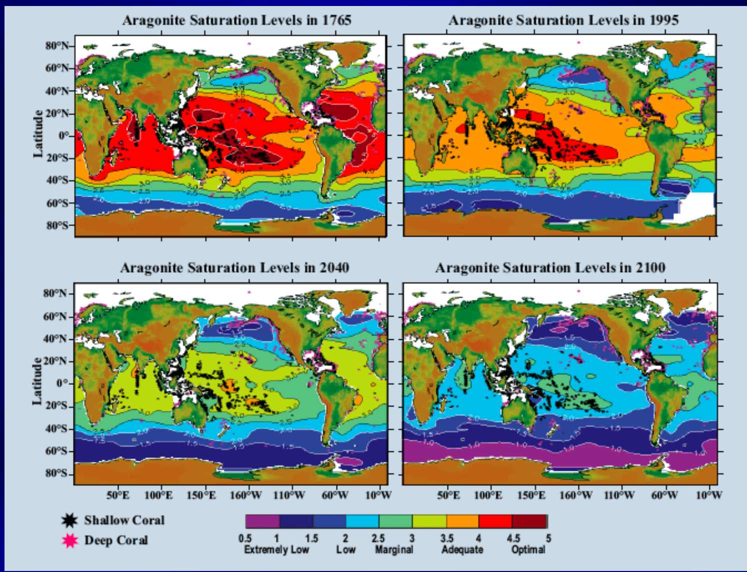
Coral reef communities (**warm waters**) might be particularly at risk.



"These experimental results provide support for the conclusion that some net calcifying communities could become subject to net dissolution in response to anthropogenic ocean acidification within this century."

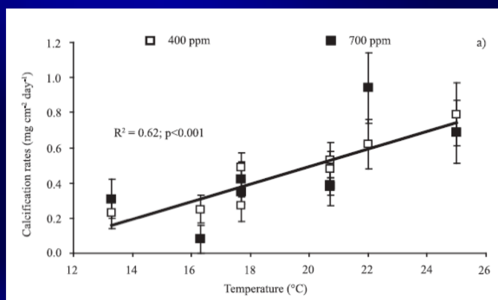
Andersson et al. 2009

Impact of OA: calcification



Impact of OA: calcification

Some studies showed no effect

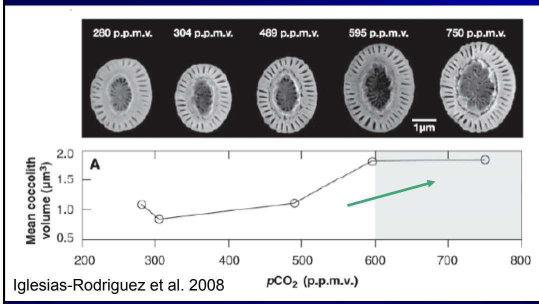


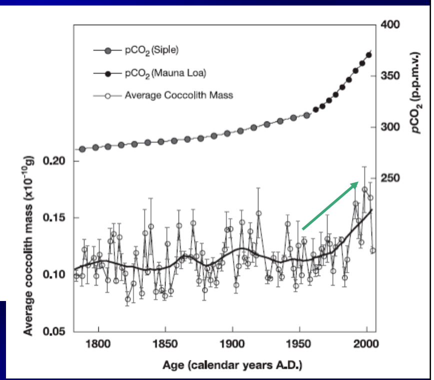
“The lack of sensitivity of **temperate corals** to high-pCO2 levels might be due to its **slow growth rates**, which seem to be more dependent on temperature than on the saturation state of calcium carbonate (in the range predicted for the end of the century)”.

Rodolfo-Metalpa et al. 2009

Impact of OA: calcification

Some studies show positive calcification responses to OA





Calcification increment of *Emiliania huxleyi* at higher CO_2 conditions.

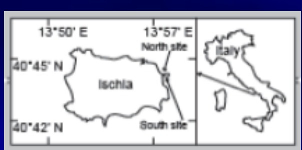
Related with the fact that coccolitophores are autotrophic and their calcification is intracellular?

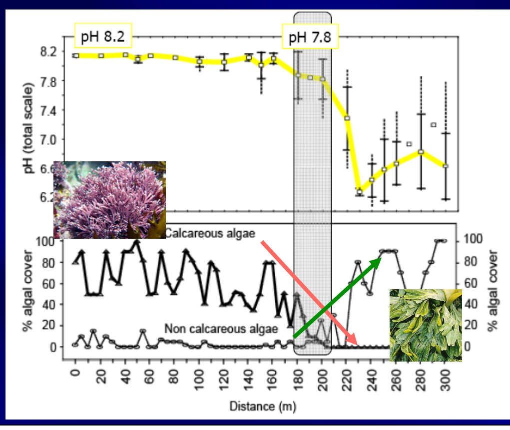
See also Halloran et al. 2008 and Grelaud et al. 2009 for similar results

Impact of OA on marine organisms

Field studies: Hall-Spencer et al. 2008 (Nature)

CO_2 volcanic vents (Ischia, Italy): 30% of biodiversity reduction at pH=7.8.





Impact of OA on marine organisms

Calcifiers present different responses toward OA. WHY?

There can be differences because:

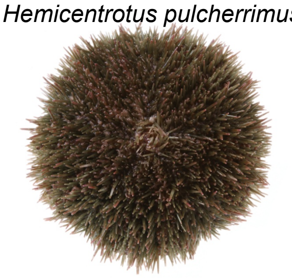
- the organisms are autotrophic or heterotrophic
- of biocalcification mechanisms (extracellular, intracellular, intercellular)
- of life stages
- of metabolic strategies
- of life strategies (that may lead to differences in acclimation and/or adaptation mechanisms)
- of ACID BASE regulation

Impact of OA: reproduction

OA can have an impact on the physiology of marine organisms, not only on the calcification...

Some examples:

Hemicentrotus pulcherrimus

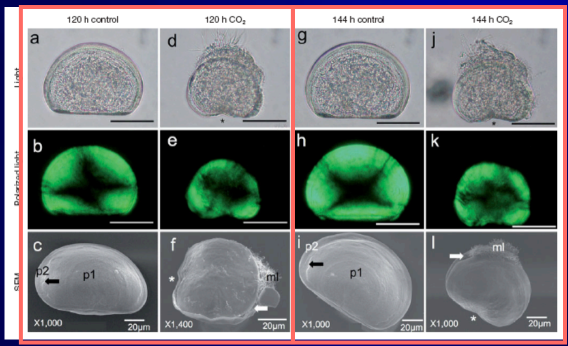


Sea urchins:

Hemicentrotus pulcherrimus
8 months at pH=7.8
($p$$CO_2$=1000ppm)
Growth not affected
Gonodal development affected
Kurihara 2008

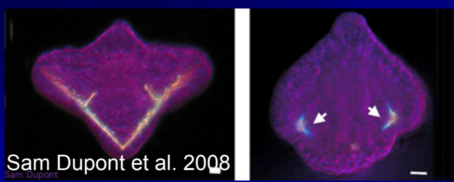
Impact of OA: reproduction

Larval stages are very sensitive to OA:



Early development of *Mytilus galloprovincialis.* Morphology of larvae incubated for 120h and 144h control (380ppm; pH=8.13) or in CO_2 seawater (2000ppm; pH=7.42).

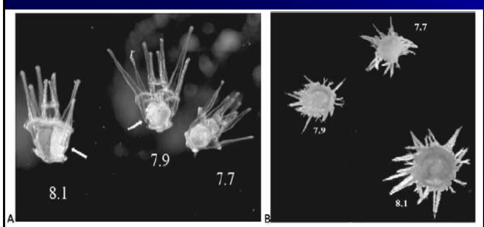
Kurihara et al. 2008



Early larvae of the brittlestar *Ophiothrix fragilis* reared in control seawater (pH 8.1, left), and water acidified with CO2 (pH 7.7 right), with a reduced skeleton as an effect.

Impact of OA: reproduction

Strongylocentrotus droebachiensis and larval development

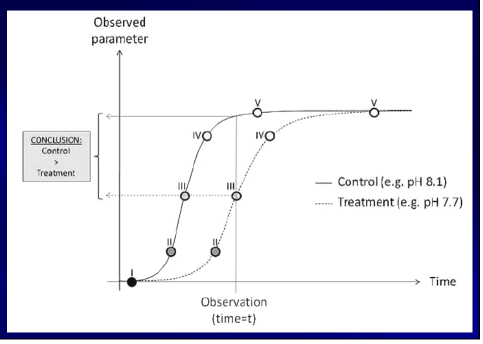


Larvae cultured at different pH (control 8.1, 7.9 and 7.7) show a developmental delay with decreasing pH.

Dupont & Thorndyke 2008

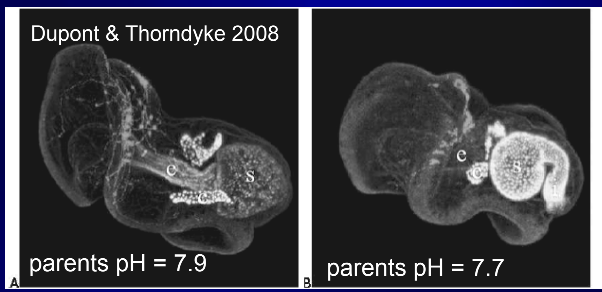
A) Late pluteus larvae - 21 days
B) Juveniles - 50 days

Relation between time and stage of development.



Impact of OA: reproduction

Asterias rubens: larvae from parents exposed to lower pH revealed lack of feeding ability.

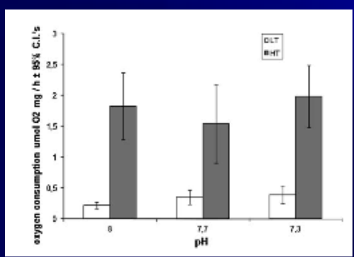


Bipinnaria larvae (7 days) after pre-exposure to low pH waters of the parents for 4 months prior to spawning.

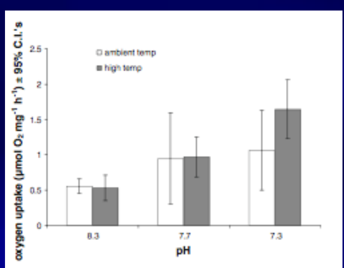
The Insulin Growth Factor II (IGFII) is revealed using antibody labeling. In the control (A), IGFII is expressed in the esophagus (e) and the coelom (c) while at low pH (7.7, B) it is expressed in the stomach (s), the intestine (i) and the coelom (c).

Impact of OA : metabolism

Oxygen consumption



Ophiura ophiura, temperate, Wood et al 2010

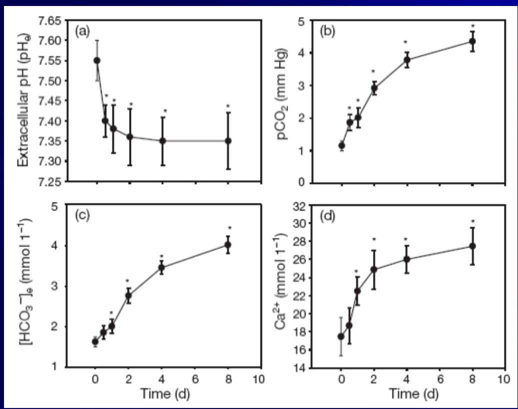


Ophiocten sericeum, arctic, Wood et al 2011

Effect on respiration differs according to species

Impact of OA : metabolism

Mytilus galloprovincialis



Michaelidis et al. 2005

Hypercapnia (pH_{SW}=7.3) causes in haemolymph:

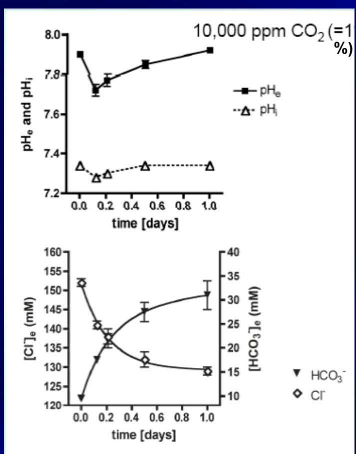
- lowered extracellular pH
- elevated pCO_2
- HCO_3^- accumulation
- Ca^{2+} accumulation

Extracellular acidosis is not compensated

Hypercapnia - excess of CO2 in the body fluids (e.g. blood)

Impact of OA : metabolism

Gadus morhua
Larsen et al. 1997



Full compensation of extracellular acidosis.

Some questions:

- Lower sensitivity than in invertebrates?
- Decrease in performance depending on pH regulation capacity?
- Can organisms spend more energy maintaining their acid-base balance and if yes for how long?

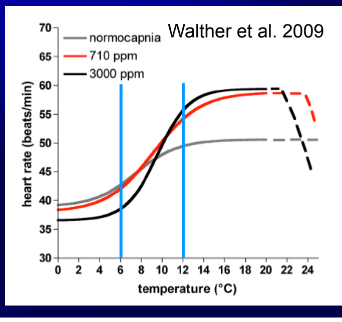
More studies needed

Impact of OA

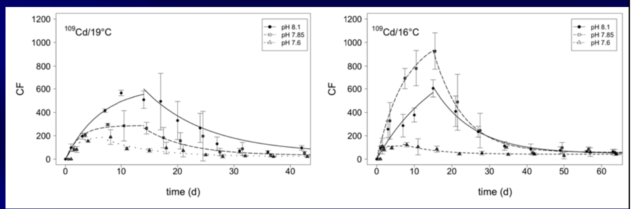
Interactions between OA and other stressors:

Spider crab
Hyas araneus

Schematic model of heart rate



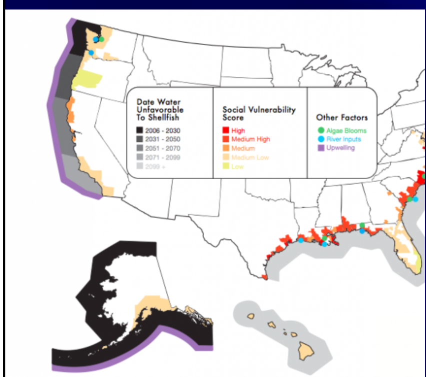
Cuttlefish
Sepia officinalis



Cd uptake kinetics in the eggshell from eggs exposed at 3 different pH and 2 temperatures. Lacoue-Labarthe et al. 2009

Impact of OA

OA can also have social and economic consequences, as, for example, fishery stocks might be affected.

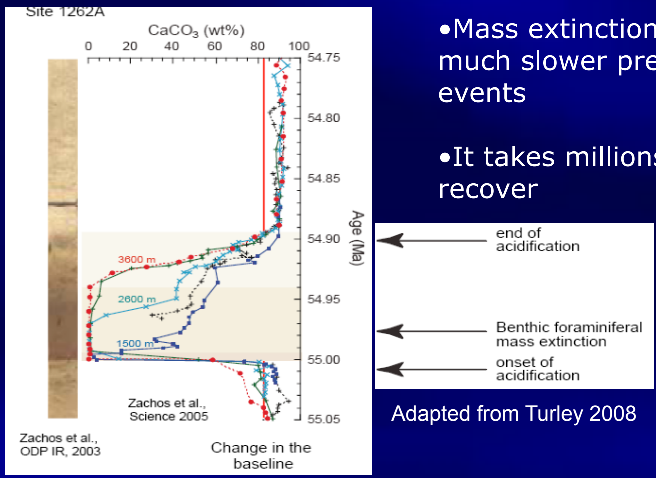


Impacts of OA and climate change on fisheries can be indirect as a species loss causes great instability on the ecosystem.
Furthermore, some species of seafood (shellfish) might be at direct risk.

Impact of OA

Lessons from the past:

The Paleocene-Eocene Thermal Maximum (PETM)

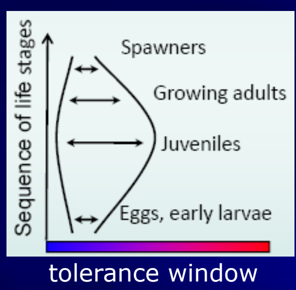


Adapted from Turley 2008

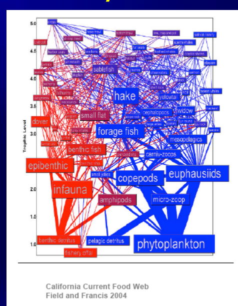
- Mass extinctions linked to much slower previous OA events
- It takes millions of years to recover

Impact of OA

Larval stages ≠ Adults ≠ Species → Species interactions within ecosystems



Adapted from Pörtner and Farrel 2008



Will organisms be able to **acclimate** and/or **adapt** to these new seawater chemical changes?

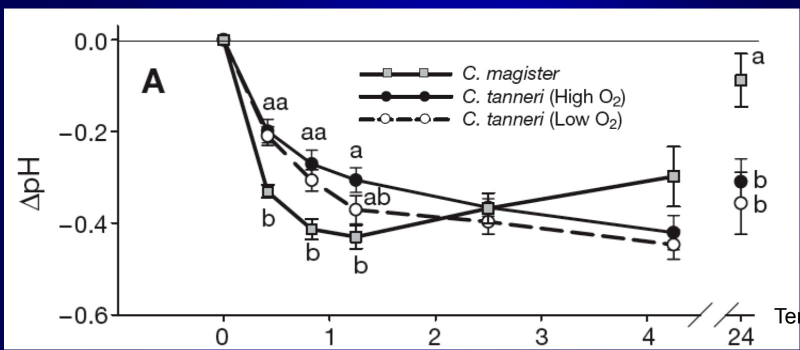
Impact of OA

Acclimation - the progressive adjustments of an organism to any change in the environment that subjects it to physiological stress. It occurs in a **short period of time (days/weeks-months) and within one organism's lifetime.**

≠

Adaptation - structural, physiological or behavioural characteristics of a population that allows it to be better suited for a certain environment. This process takes place over **many generations through natural selection.**

Acclimation potential differs according to species



C.magister

Crabs *Cancer magister* (intertidal) et *Chionoe tanneri* (deep) submitted to 10000ppmv (Pane & Berry 2007)

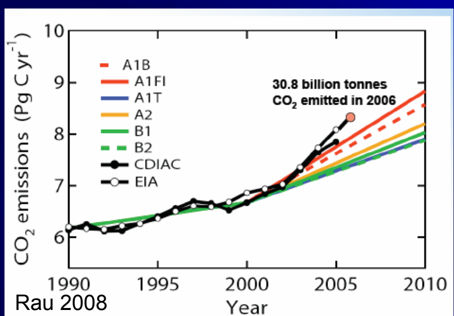
C.tanneri

Impact of OA

- Reduced calcification rates, growth, production and life span of adults, juveniles and larvae
- Reduced tolerance to other environmental fluctuations
- Combined impacts of OA and temperature increase
- Changes in fitness and survival
- Changes in species biodiversity, biogeography and food webs
- Shifts in ecosystems: some species will “win” and some will “loose”

Uncertainties are great – RESEARCH NEEDED

Reducing CO_2 emissions…



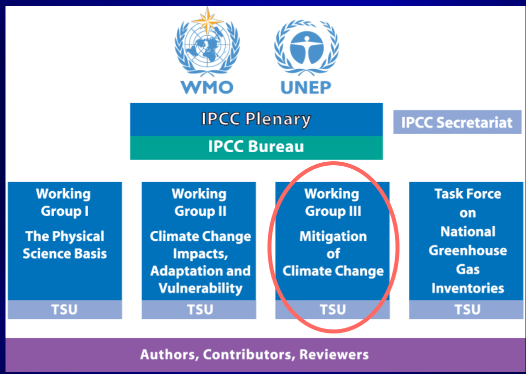
Rau 2008

Efforts to reverse CO2 emissions have so far failed: Emissions for 2000-2007 were well above worst case scenarios!

Why is it so hard to deal with the CO_2 emissions problem?

- Because it implies global awareness and behavioural changes
- Because it is initially costly
- Because human population is growing fast and there is a high energy demand

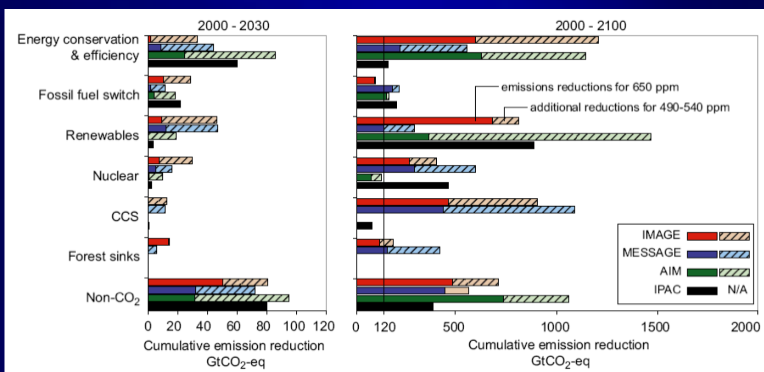
Reducing CO_2 emissions...



Peace Nobel Prize 2007

The **Intergovernmental Panel of Climate Change (IPCC)** is the leading **scientific** body for the assessment of climate change.

Reducing CO_2 emissions...



Illustrative scenarios from 4 models aiming at the stabilization at low (490–540 ppm CO_2-eq - light bars) and intermediate levels (650 ppm CO2-eq - dark bars) respectively.

IPCC 2007

CCS: CO_2 capture and storage Non-CO_2: N_20, CH_4 (15% GhG)

Reducing CO_2 emissions…

Smart Solutions:

CO_2 emissions cut = fossil fuels consumption reduction + increasing the use of renewable energy sources

Measures providing the **cheapest** mitigation options (IPCC 2007) for developed and developing countries as well as for transition economies.

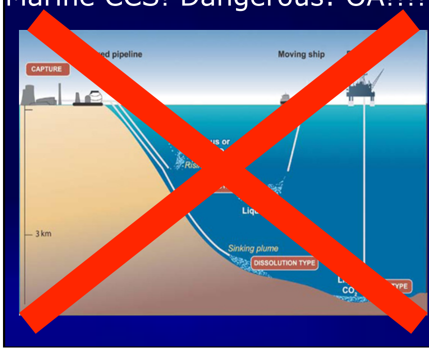
Economic region	Countries/country groups reviewed for region	Potential as % of national baseline for buildings[b]	Measures covering the largest potential	Measures providing the cheapest mitigation options
Developed countries	USA, EU-15, Canada, Greece, Australia, Republic of Korea, United Kingdom, Germany, Japan	Technical: 21%-54%[c] Economic (<US$ 0/tCO_2-eq): 12%-25%[d] Market: 15%-37%	1. Shell retrofit, inc. insulation, esp. windows and walls; 2. Space heating systems; 3. Efficient lights, especially shift to compact fluorescent lamps (CFL) and efficient ballasts.	1. Appliances such as efficient TVs and peripherals (both on-mode and standby), refrigerators and freezers, ventilators and air-conditioners; 2. Water heating equipment; 3. Lighting best practices.
Economies in Transition	Hungary, Russia, Poland, Croatia, as a group: Latvia, Lithuania, Estonia, Slovakia, Slovenia, Hungary, Malta, Cyprus, Poland, the Czech Republic	Technical: 26%-47%[e] Economic (<US$ 0/tCO_2eq): 13%-37%[f] Market: 14%	1. Pre- and post- insulation and replacement of building components, esp. windows; 2. Efficient lighting, esp. shift to CFLs; 3. Efficient appliances such as refrigerators and water heaters.	1. Efficient lighting and its controls; 2. Water and space heating control systems; 3. Retrofit and replacement of building components, esp. windows.
Developing countries	Myanmar, India, Indonesia, Argentine, Brazil, China, Ecuador, Thailand, Pakistan, South Africa	Technical: 18%-41% Economic (<US$ 0/tCO_2eq): 13%-52%[g] Market: 23%	1. Efficient lights, esp. shift to CFLs, light retrofit, and kerosene lamps; 2. Various types of improved cooking stoves, esp. biomass stoves, followed by LPG and kerosene stoves; 3. Efficient appliances such as air-conditioners and refrigerators.	1. Improved lights, esp. shift to CFLs light retrofit, and efficient kerosene lamps; 2. Various types of improved cooking stoves, esp. biomass based, followed by kerosene stoves; 3. Efficient electric appliances such as refrigerators and air-conditioners.

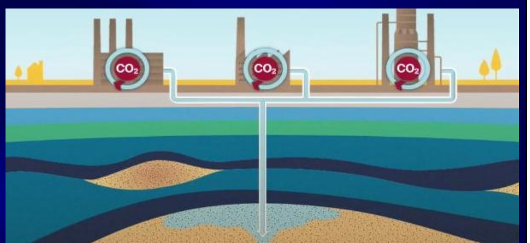
Reducing CO_2 emissions…

Smart Solutions - New technologies

Energy efficiency + **Renewable energy** + **CO_2 capture and storage (CCS)**

Marine CCS! Dangerous: OA!!!!





Geo-sequestration - potential risk of leakage, but for well chosen places IPCC estimates that CO_2 could be trapped for millions of years

Reducing CO_2 emissions...

How about Ocean Acidification?

Atmospheric CO_2 stabilization and ocean acidification

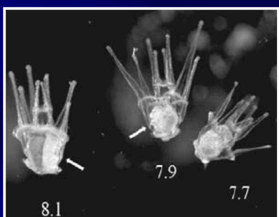
Long Cao[1] and Ken Caldeira[1] 2008

- **Stabilization level should be lower than 450 ppm and should not be chosen based on climate considerations alone.**

Oceans will become more acidic:
very high certainty.

The only way of reducing the impact of global ocean acidification is a substantial and urgent reduction in CO_2 emissions:
very high certainty.

Mitigation will make a difference:
OA might stabilize at CO_2 *lower* than 450 ppm



Dupont & Thorndyke 2008