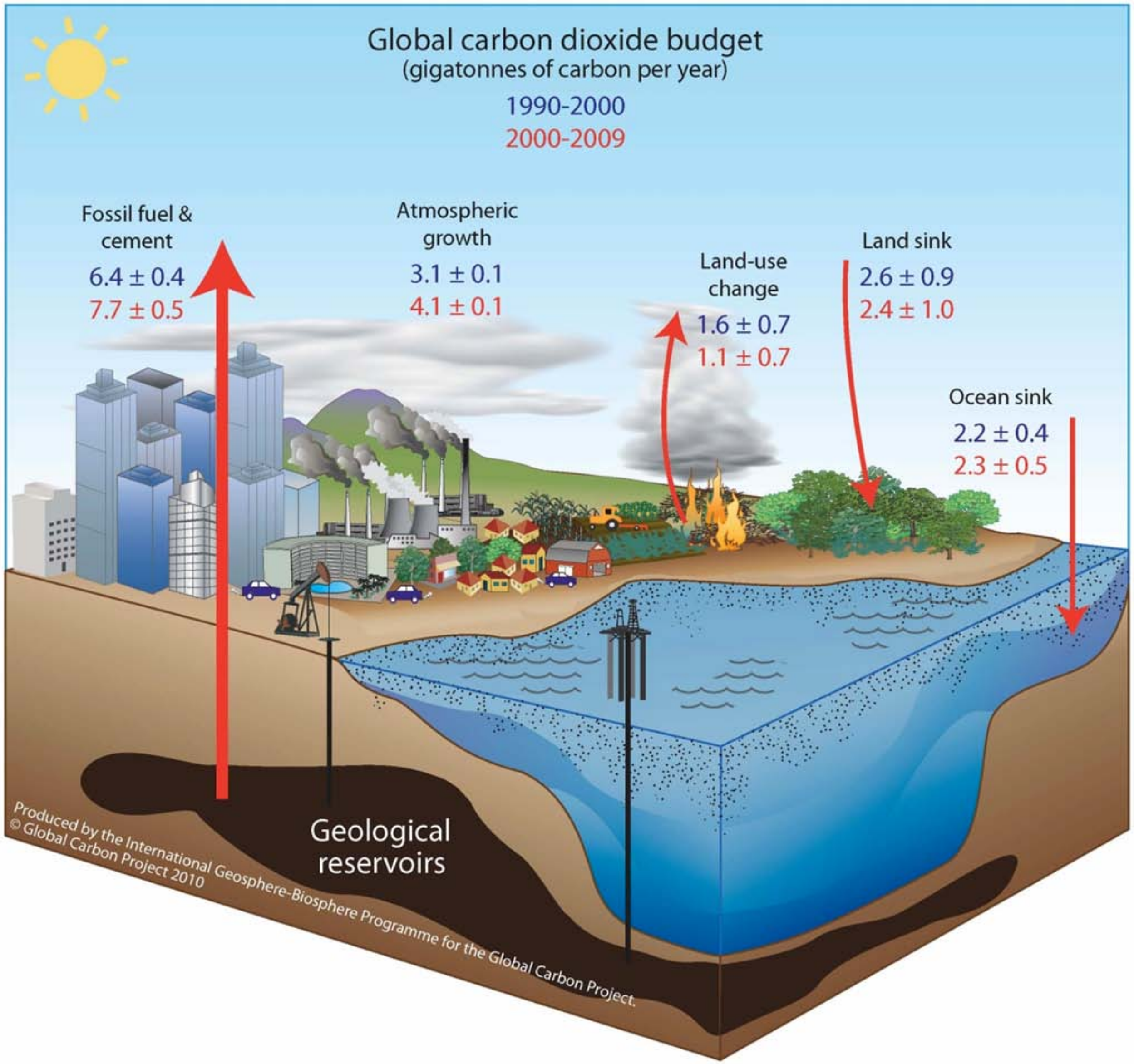
Ocean acidification: a biogeological perspective

Jelle Bijma (AWI, Bremerhaven, Germany)

- Ocean acidification: present and future . . . . .
- Why a biogeological perspective?
- Ocean acidification in the past . . . . .
- Consequences for Biodiversity . . . . .

Seventh EGU Alexander von Humboldt International Conference on Ocean acidification: consequences for marine ecosystems and society. Penang, June 20

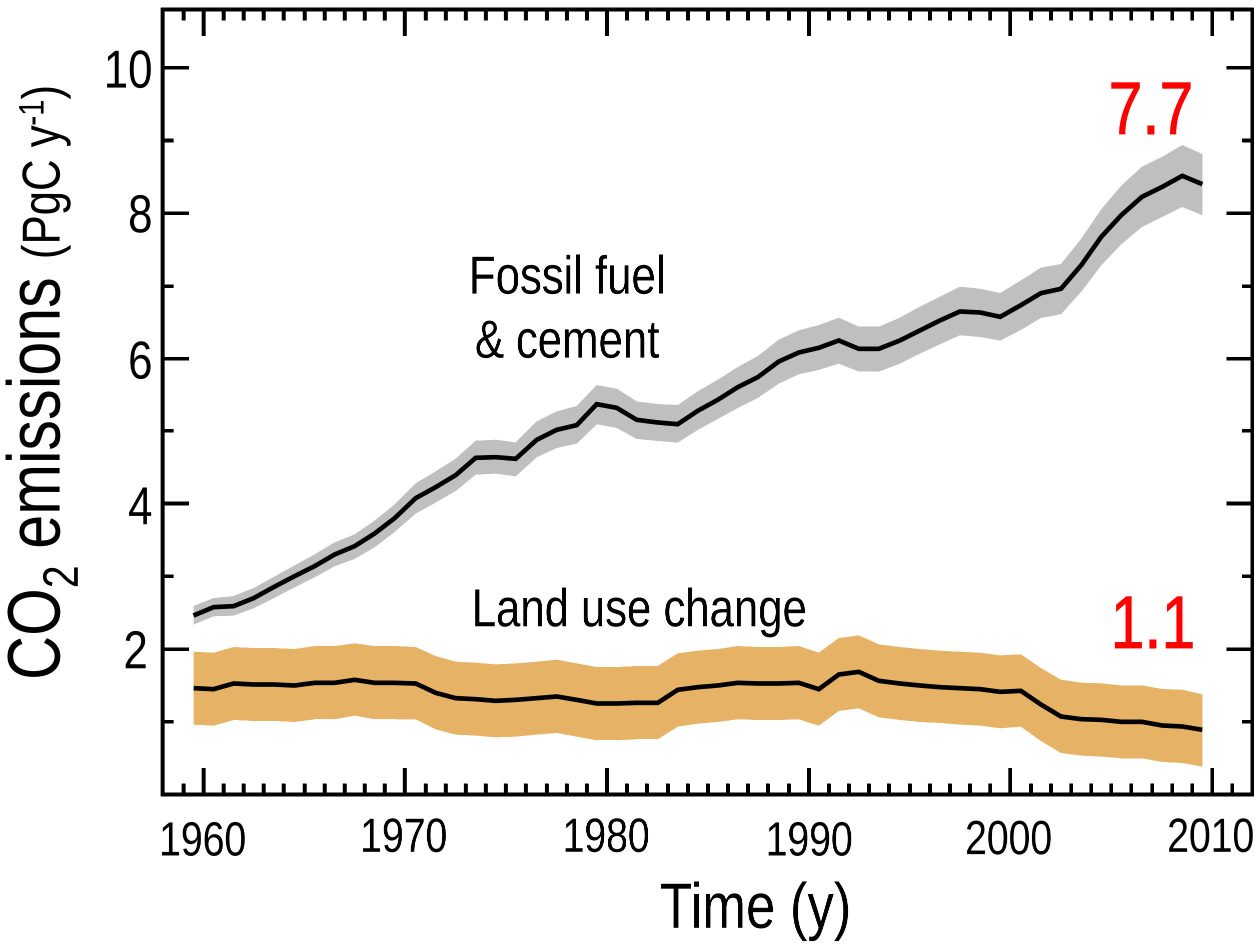
Anthropogenic Global Carbon Dioxide Budget



CO_2 Emissions from Land Use Change (1960-2009)

[1 Pg = 1 Petagram = 1 Billion metric tonnes = 1 Gigatonne = 1×10^{15}g]

Average (2000-2009)



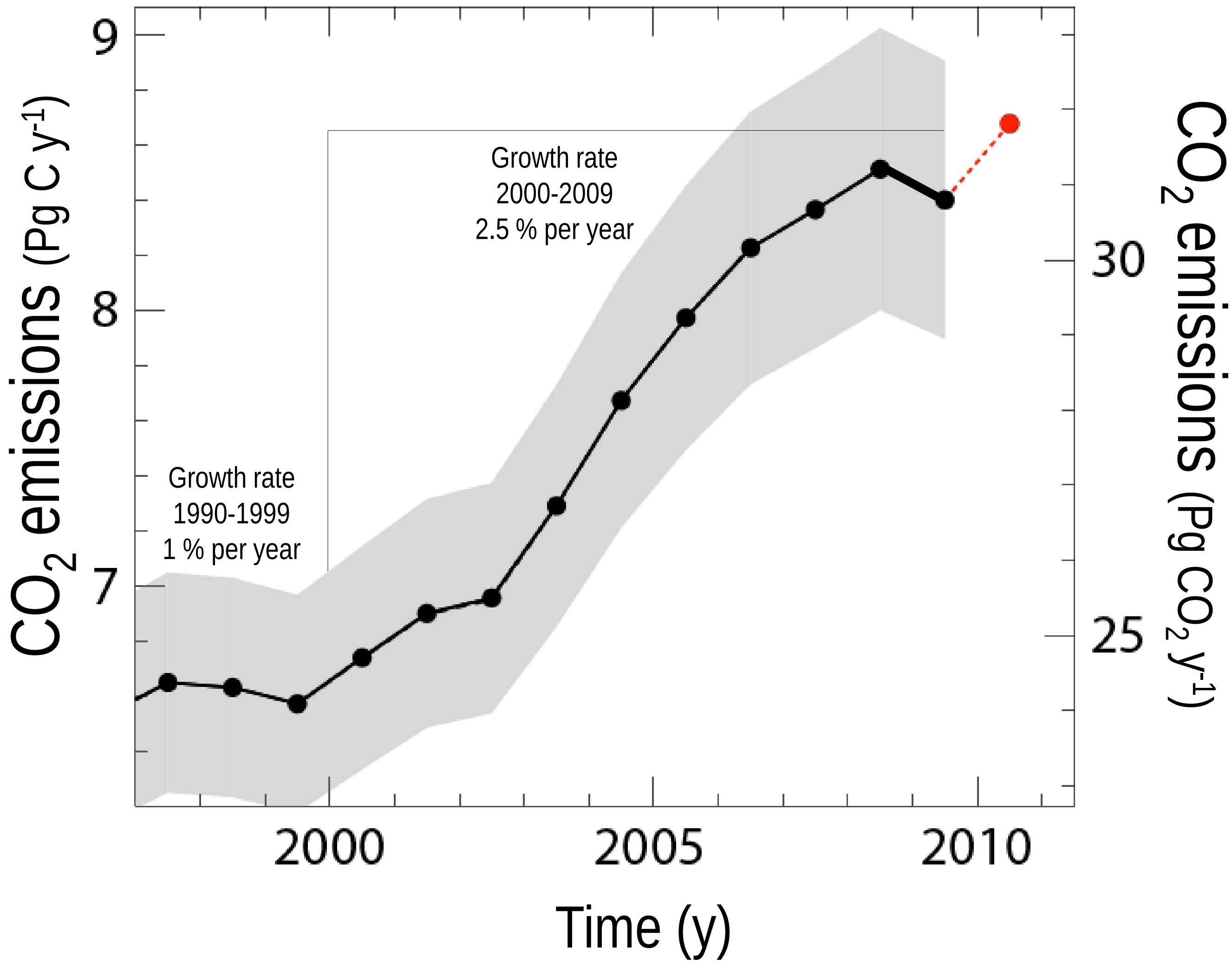
8.8 PgC y^{-1}

LUC emissions now
~10% of total CO_2 emissions

Updated from Le Quéré et al. 2009, Nature Geoscience

Fossil Fuel CO_2 Emissions

[1 Pg = 1 Petagram = 1 Billion metric tonnes = 1 Gigatonne = $1x10^{15}$g]



2009:
Emissions:8.4 0.5 PgC
Growth rate: -1.3%
1990 level: +37%

2000-2008
Growth rate: +3.2%

2010 (projected):
Growth rate: >3%

Friedlingstein et al. 2010, Nature Geoscience; Gregg Marland, Thomas Boden-CDIAC 2010

Fate of Anthropogenic CO_2 Emissions (2000-2009)

1.1 0.7 PgC y^{-1}

+

7.7 0.5 PgC y^{-1}

4.1 0.1 PgC y^{-1}

47%

2.4 PgC y^{-1}

27%

Calculated as the residual of all other flux components

26%

2.3 0.4 PgC y^{-1}

Average of 5 models

Global Carbon Project 2010; Updated from Le Quéré et al. 2009, Nature Geoscience; Canadell et al. 2007, PNAS

Fate of Anthropogenic CO_2 Emissions (20?0-2009)

1.1 0.7 PgC y^{-1}

4.1 0.1 PgC y^{-1}

47%

7.7 0.5 PgC y^{-1}

+

C y^{-1}

7%

Calcula s the dual o
all ot lux co nents

26%

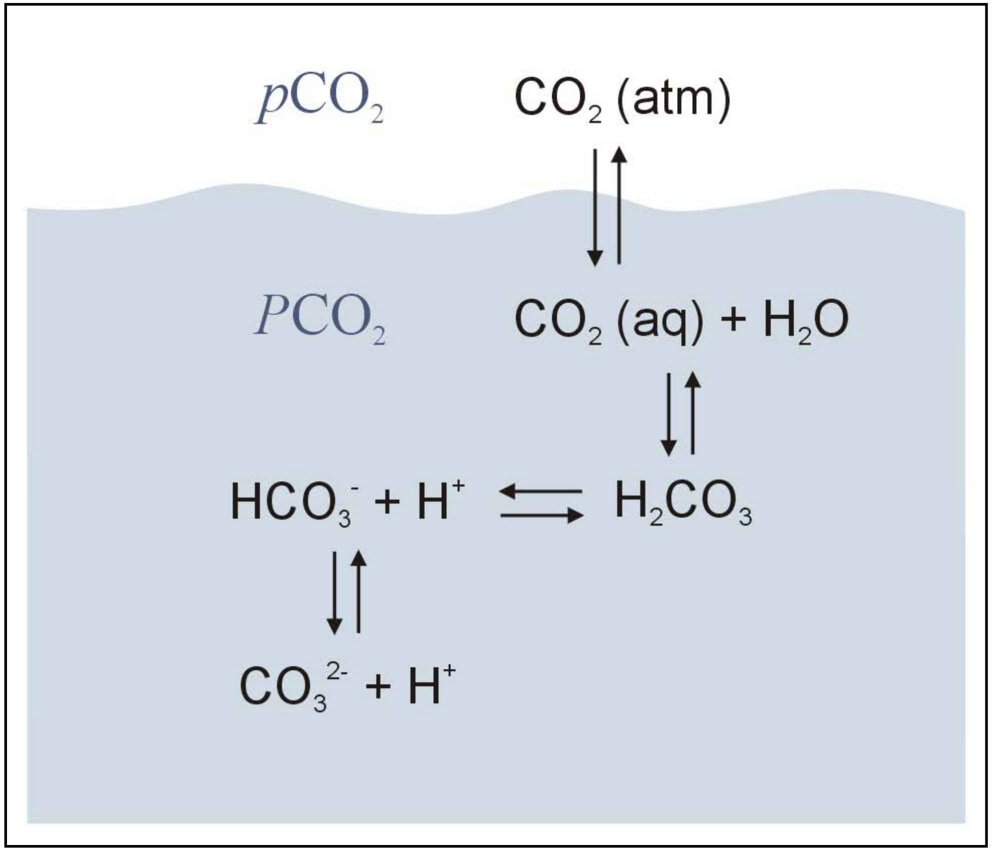
2.3 0.4 PgC y^{-1}

Average of 5 models

Double trouble

Global Carbon ct 2010; Updated from Le Quéré et al. 2009, Nature Geoscience; Canadell et al. 2007, PNAS

The marine carbonate system



CO_2 (aq): aqueous carbon dioxide

HCO_3^-: bicarbonate ion

CO_3^{2-}: carbonate ion

H_2CO_3: carbonic acid

ΣCO_2 or DIC or TCO_2:

Total dissolved inorganic carbon

$$\Sigma CO_2 = [HCO_3^-] + [CO_3^{2-}] + [CO_2(aq)] + [H_2CO_3]$$

~90% ~10% <1%

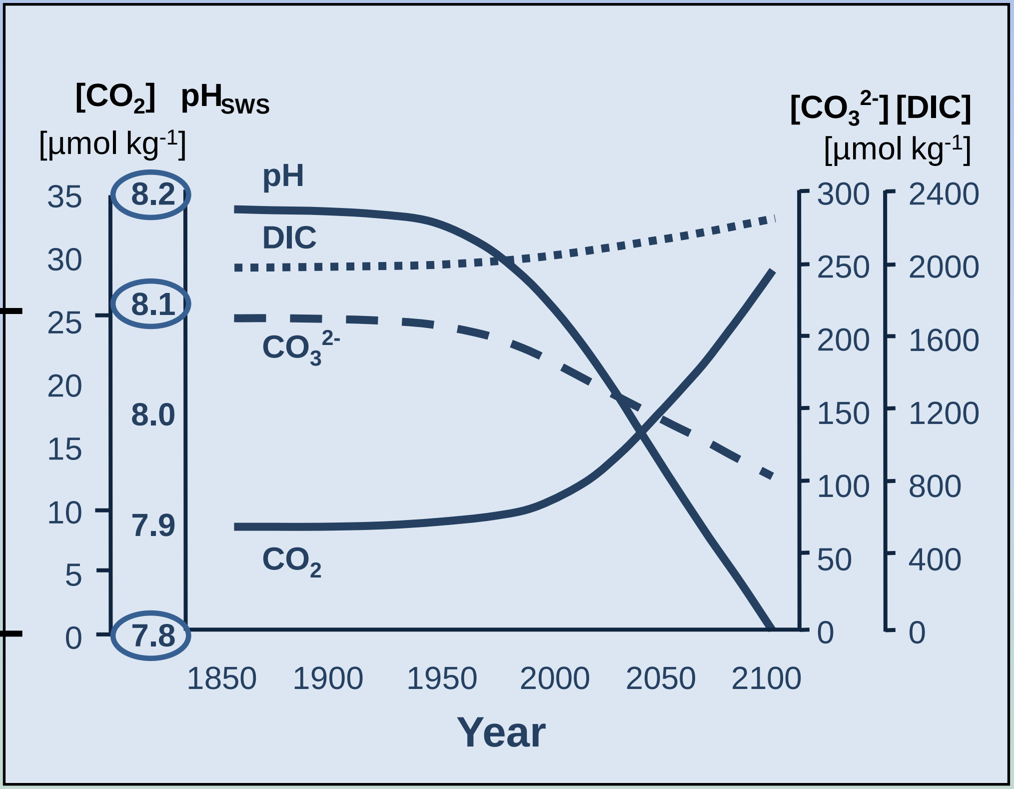
Ocean Acidification

Changes in surface ocean chemistry based on the IS92a scenario IPCC report 1995 (linear increase from 6.3 GtC yr^{-1} to 20 GtC yr^{-1} in the year 2100).

30%

more acidic!

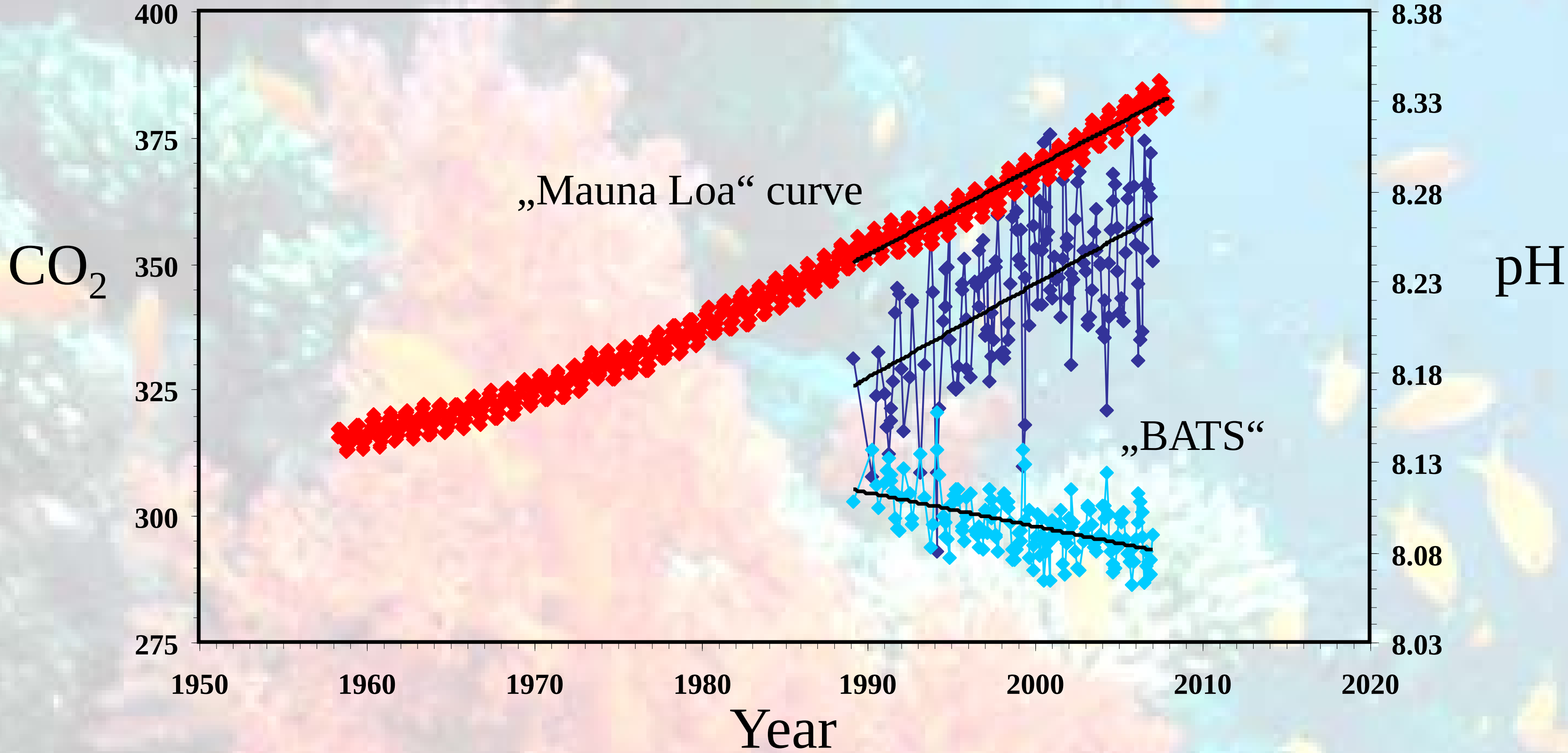
150%



Wolf-Gladrow et al., 1999

What we know about ocean CO_2 chemistry

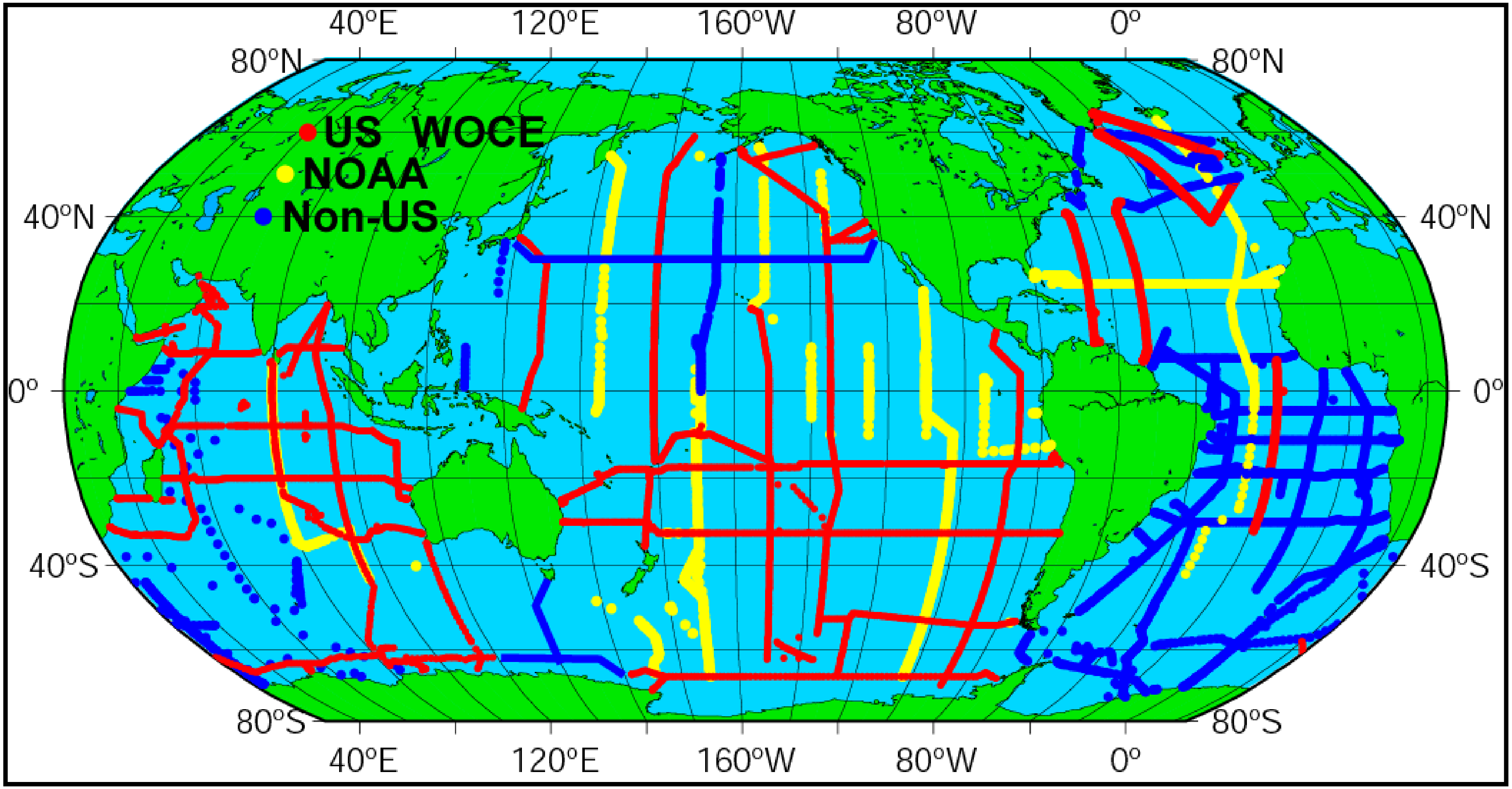
…from time series stations



Courtesy: Richard A. Feely
NOAA/Pacific Marine Environmental Laboratory

What we know about ocean CO_2 chemistry

...from field observations



WOCE/JGOFS/OACES Global CO_2 Survey

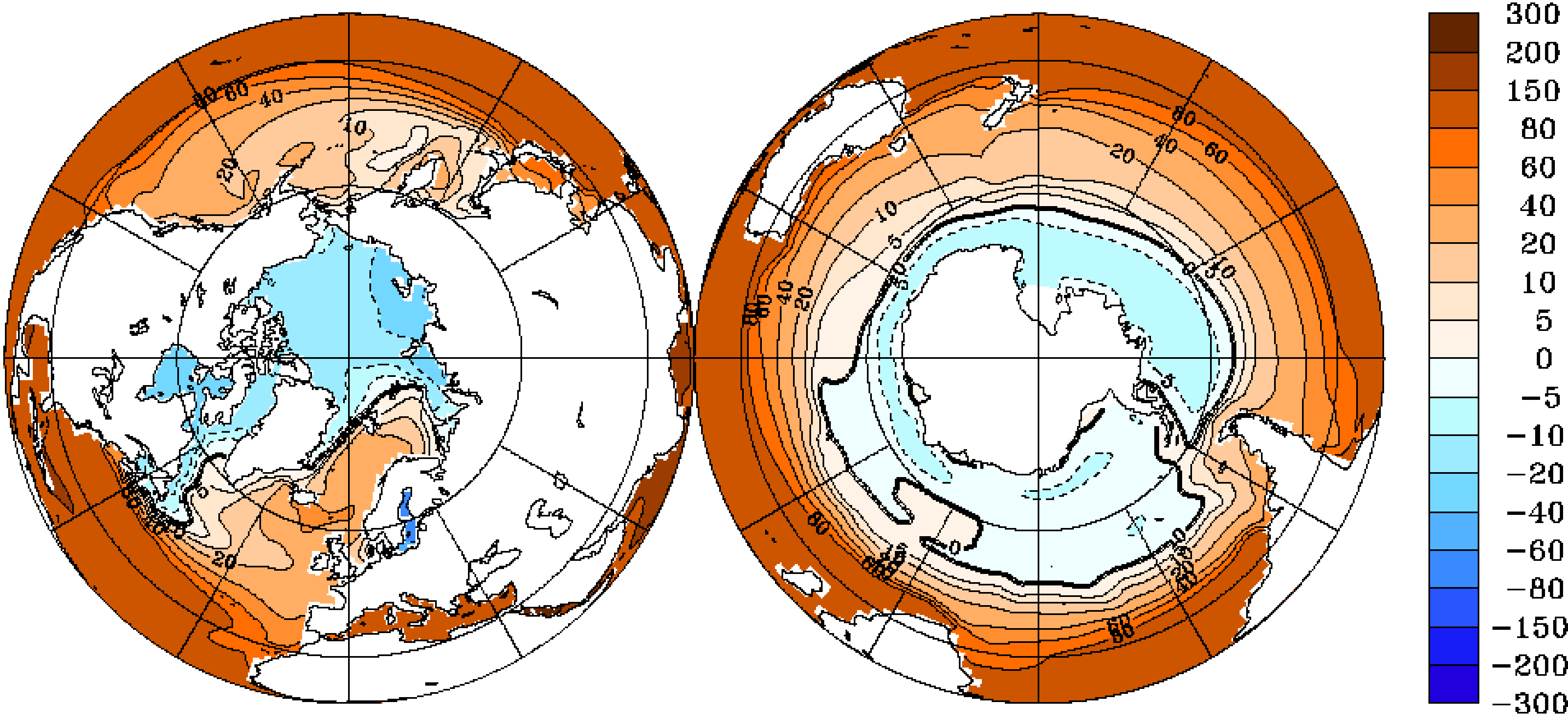
~72,000 sample locations
collected in the 1990s

DIC 2 μmol kg^{-1}
TA 4 μmol kg^{-1}

Sabine et al (2004)

Undersaturation is strongest in the high latitudes

Aragonite undersaturation $\Delta[CO_3^{2-}]_{Arag}$ at $2xCO_2$



*Model approach assuming a simulation with +1% increase per year (model results only)

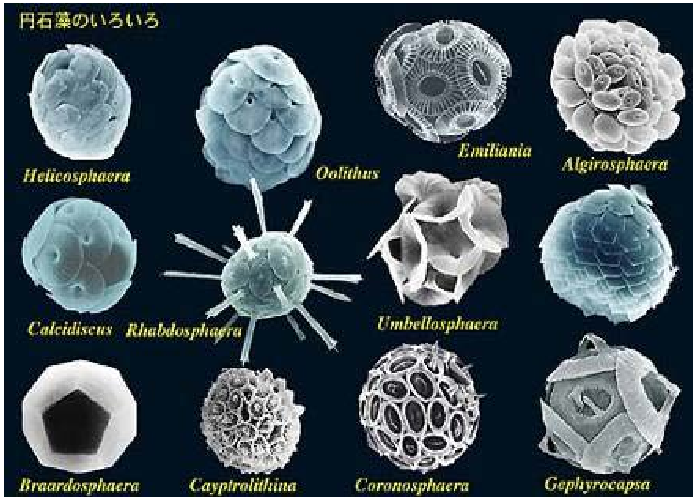
Jim Orr (CEA/IAEA)

Ocean Acidification

- Decrease in pH 0.1 over the last two centuries (30% increase in acidity; decrease in carbonate ion of about 16%)
- How will this impact marine organisms and ecosystems?

Photo: Missouri Botanical Gardens

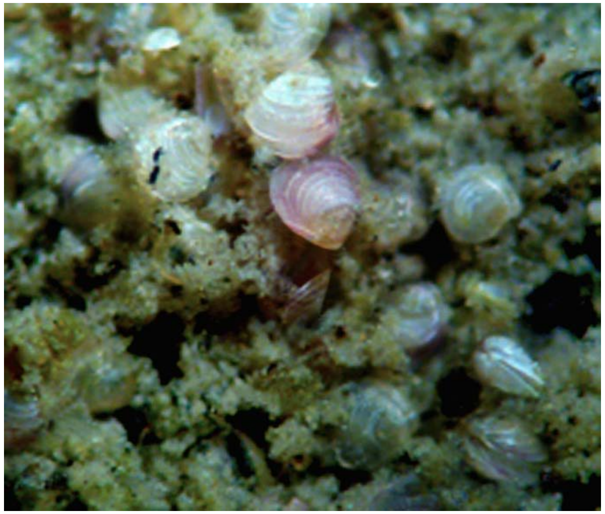
Corals



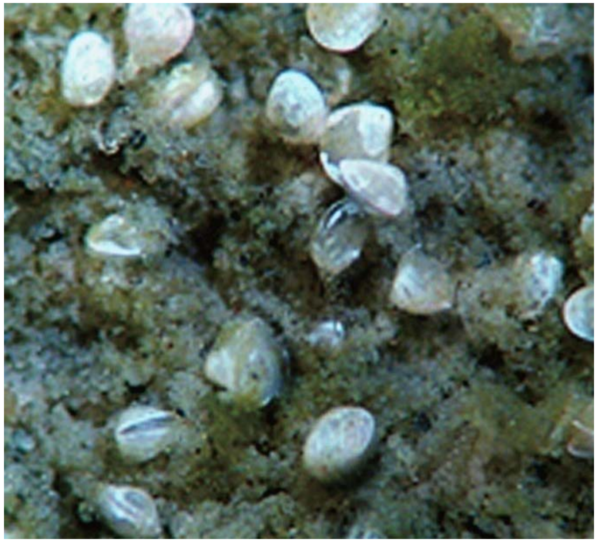
Calcareous Plankton

http://www.biol.tsukuba.ac.jp/~inouye

Bivalve juvenile stages can also be sensitive to carbonate chemistry



Control
$\Omega_A = 1.5$



$\Omega_A = 0.3$

Hard shell clam *Mercenaria*

- Common in soft bottom habitats

Used newly settled clams

- Size 0.3 mm
- Massive dissolution within 24 h in undersaturated water; shell gone w/in 2 wks
- Dissolution is source of mortality in estuaries & coastal habitats

Green et al., 2004

Potential impacts of high CO_2 on marine fauna

- Adverse effects on reproductive success
  - Decreased fertilization rates (sea urchins, bivalves)
  - Increased juvenile mortality (bivalves, sea urchins, copepods, fish larvae)

- Reduced growth in adults (sea urchins, bivalves)
- Impaired oxygen transport (squid)

- Reduced metabolism/scope for activity (squid)

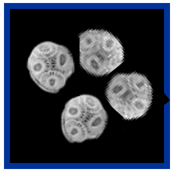
Potential Ecosystem Responses

Changes in relative abundance & distribution of calcifying species

- Non-calcifying species may outcompete calcifiers
- Geographical ranges of calcifying species may shift
- Vertical depth distributions of calcifying species may shoal with decreasing $CaCO_3$ saturation state

Changes in food webs and other species interactions

Potential Effects on Open Ocean Food Webs



Coccolithophores

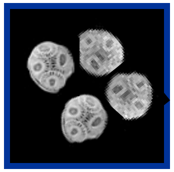
ARCOD@ims.uaf.edu

Copepods

Pacific Salmon

Vicki Fabry

Potential Effects on Open Ocean Food Webs



Coccolithophores

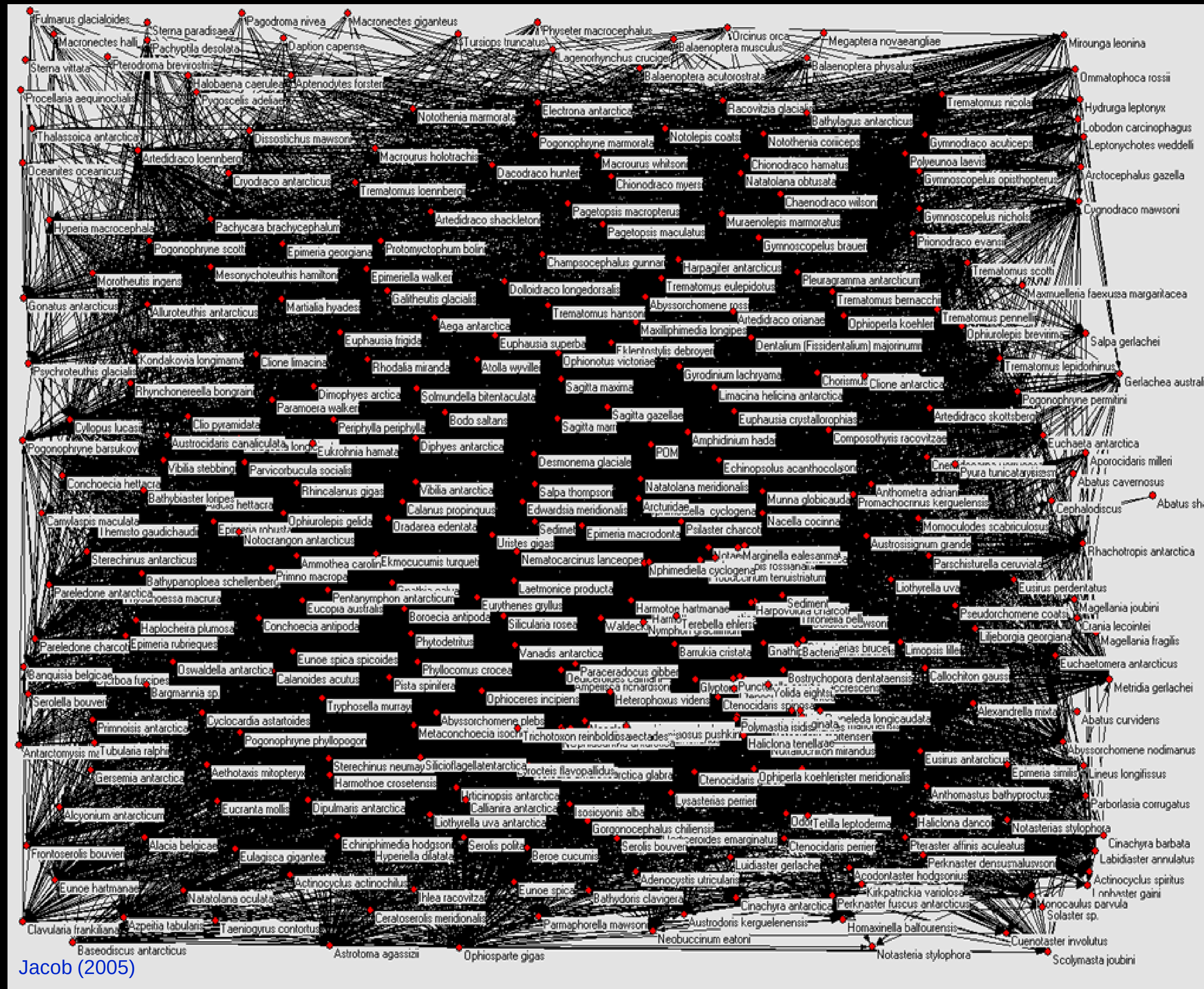
ARCOD@ims.uaf.edu

Copepods

Pacific Salmon

Vicki Fabry

Weddell Sea Food Web: 489 species (incl 62 autotrophs, >16000 trophic links (Jacob, 2005)



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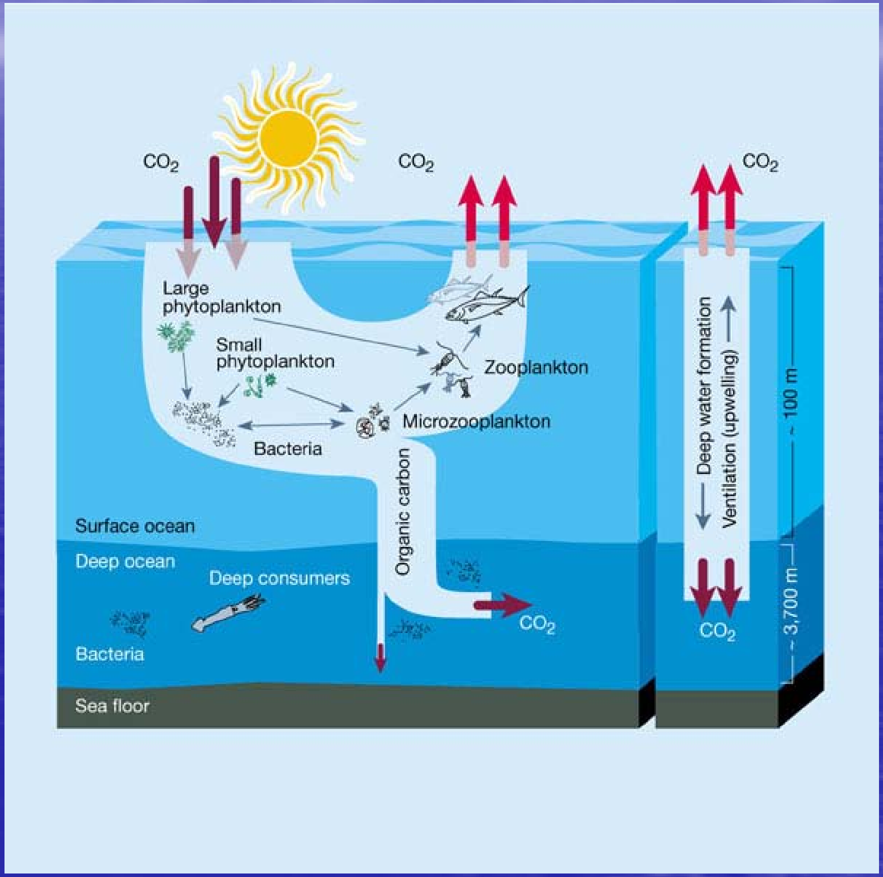
Changes in food webs and other species interactions

Impacts on biogeochemical cycles

- Speciation of nutrients and trace metals
- Changes in cycling of carbon and $CaCO_3$ within oceans (e.g. "ballasting")
- Changes in the "microbial loop"
- Feedbacks to climate

The global carbon cycle is largely driven by biology: How will the „biological pump“ respond to OA?

What happens if biology is turned of?



The „Strangelove ocean“:

- The biological pump stops
- The surface-deep CO_2 gradient disappears
- Within 250 yrs atmospheric CO_2 increases 2.4 times

see: Maier-Reimer, Mikolajewicz and Winguth (1996); Zeebe and Westbroek (2003)

Wrap up ....

- Oceans are stabilising global warming (but very slowly) ....

- At the same time are oceans acidifying (very fast) ....

- Society is facing double trouble....

Ocean acidification: a biogeological perspective

Jelle Bijma (AWI, Bremerhaven, Germany)

- Ocean acidification: present and future . . . . .
- Why a biogeological perspective?
- Ocean acidification in the past . . . . .
- Consequences for Biodiversity . . . . .

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Biological aspects

Real world

- comprises the actual complexity of the chemical, biological and ecological systems and interactions between them

Real time

- capture the time component inherent to the carbon perturbation and physiological and ecosystem response

Limitations

- gradual change makes it difficult to identify responses
- complexity of biology itself
- difficulty to capture longer term processes such as ecological adaptation, evolution and, biogeochemical cycles
- no information on recovery processes

Why paleo?

The farther backward you can look, the farther forward you are likely to see.” Winston Churchill

- What has happened *can* happen (e.g. perturbation of ocean chemistry)
- Long-term (natural) context for recent changes
- Investigate the impact on biogeochemical cycles
- Reduced complexity (integration of space and time)
- Different time scales (historical/sub-recent, G-IG, deep time,….)
- Process of recovery
- Different scenarios as case and sensitivity studies for models

Limitations

- limited biological information (hard parts and biomarkers)
- limited by accuracy of proxy reconstructions
- restrictions on temporal and spatial resolution
- no perfect analogues

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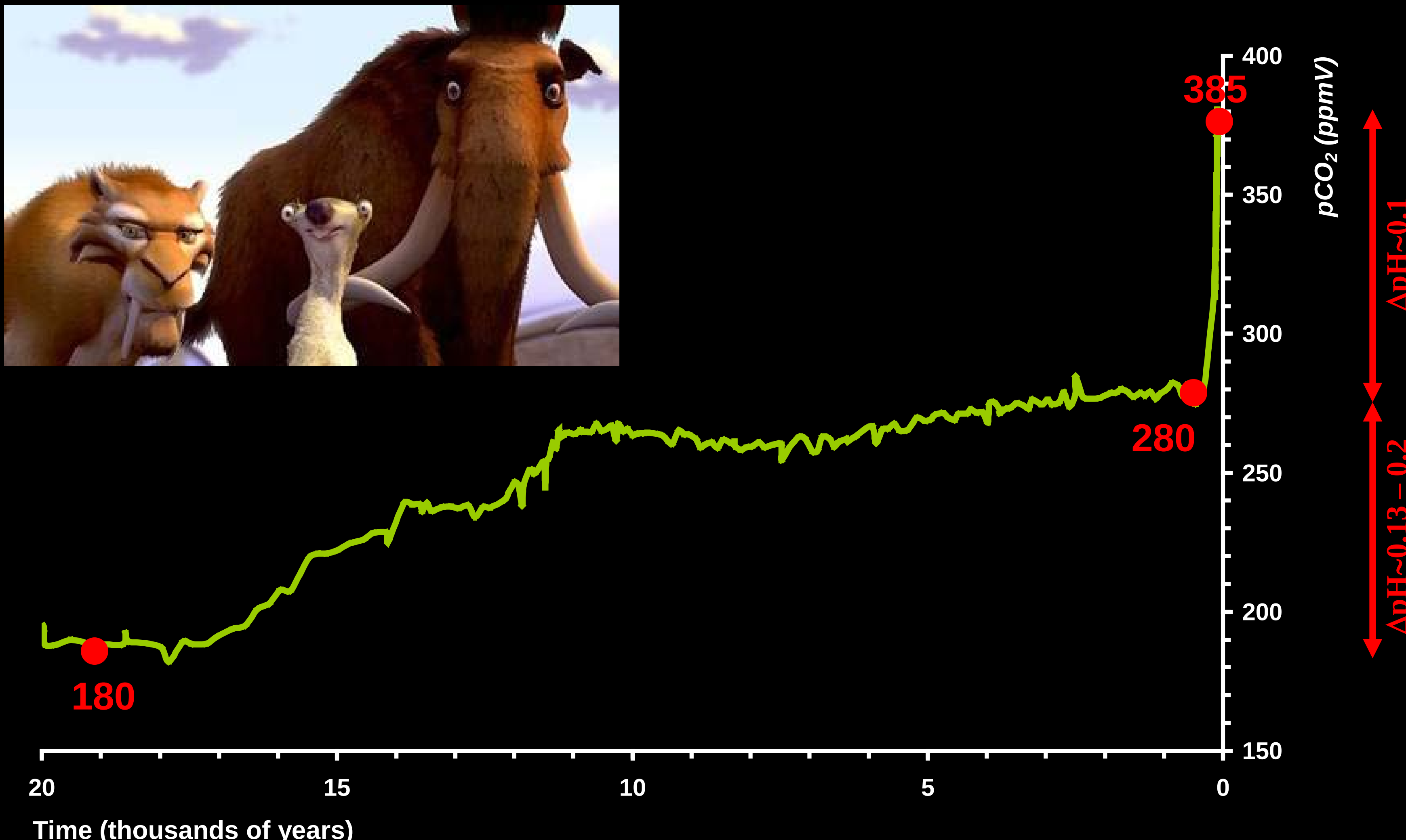
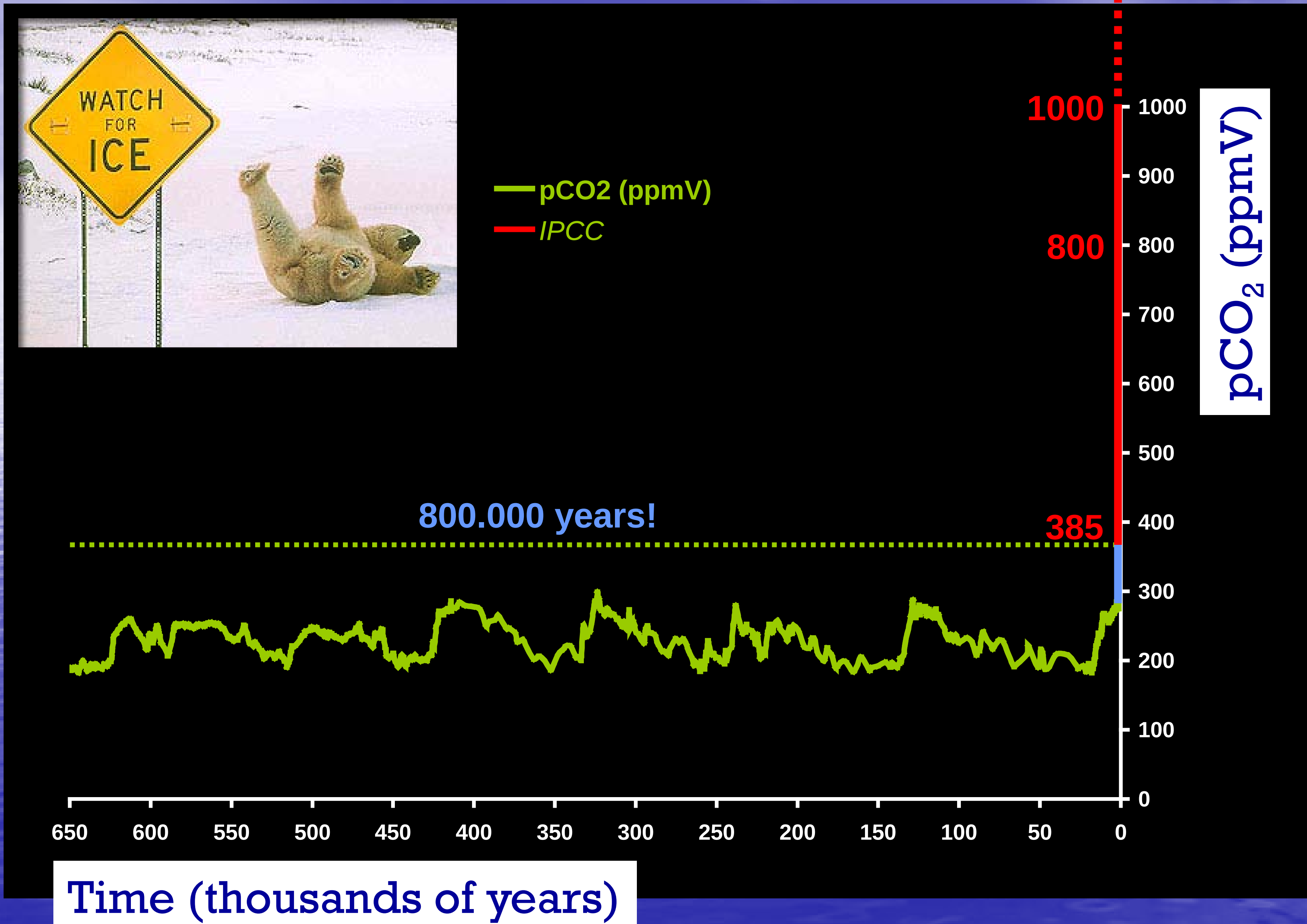
Courtesy: Henk Brinkhuis

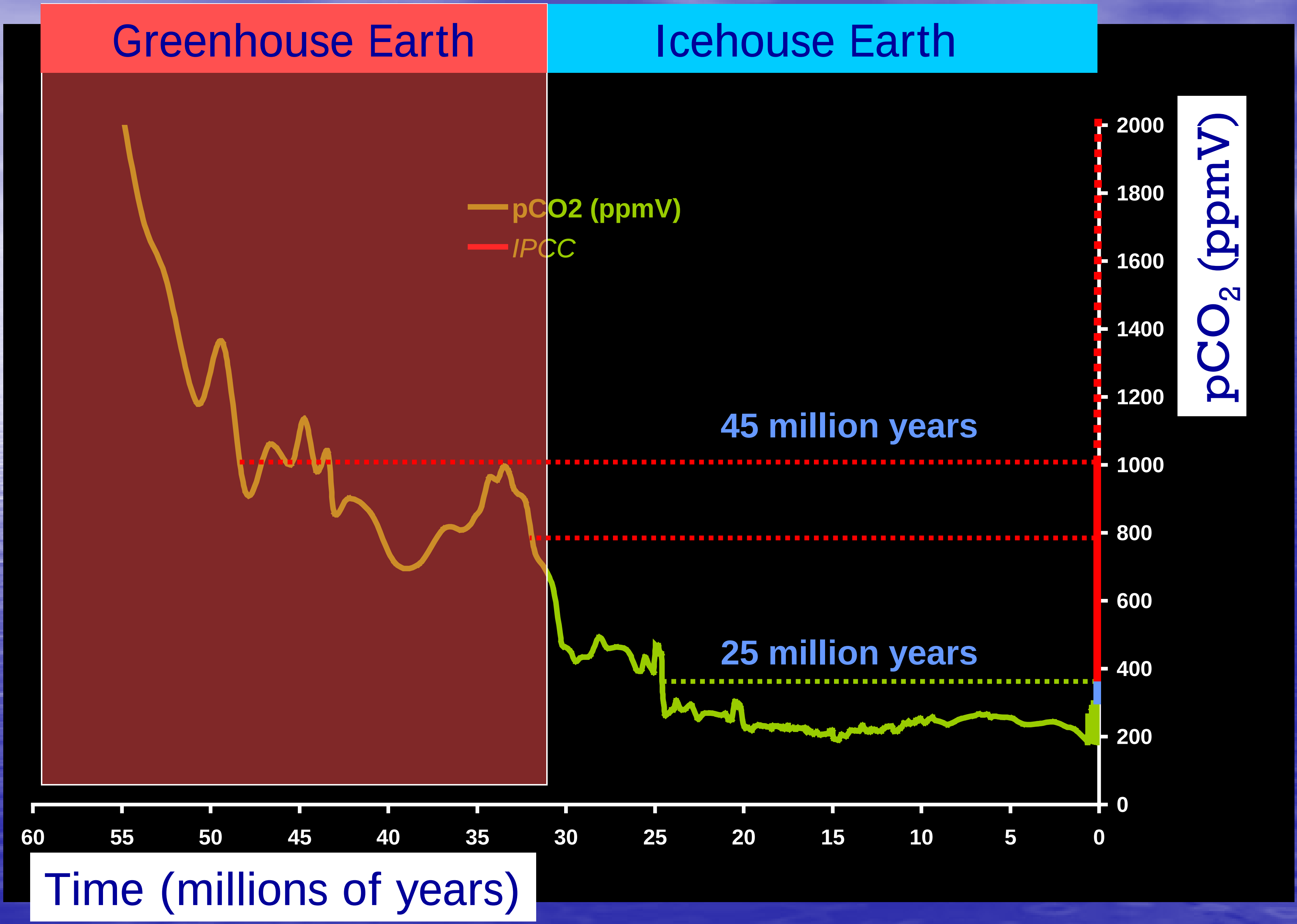
De Last Ice age



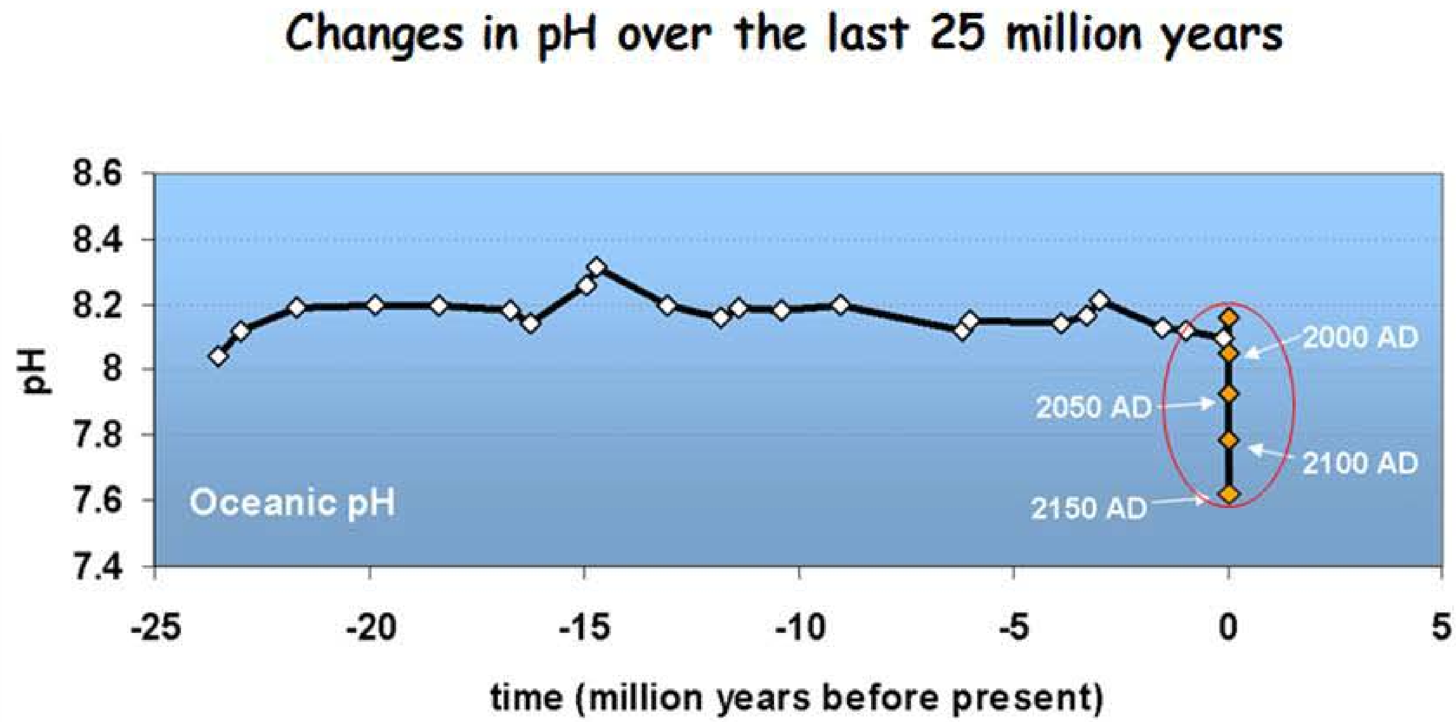
Courtesy: Henk Brinkhuis



Courtesy: Henk Brinkhuis

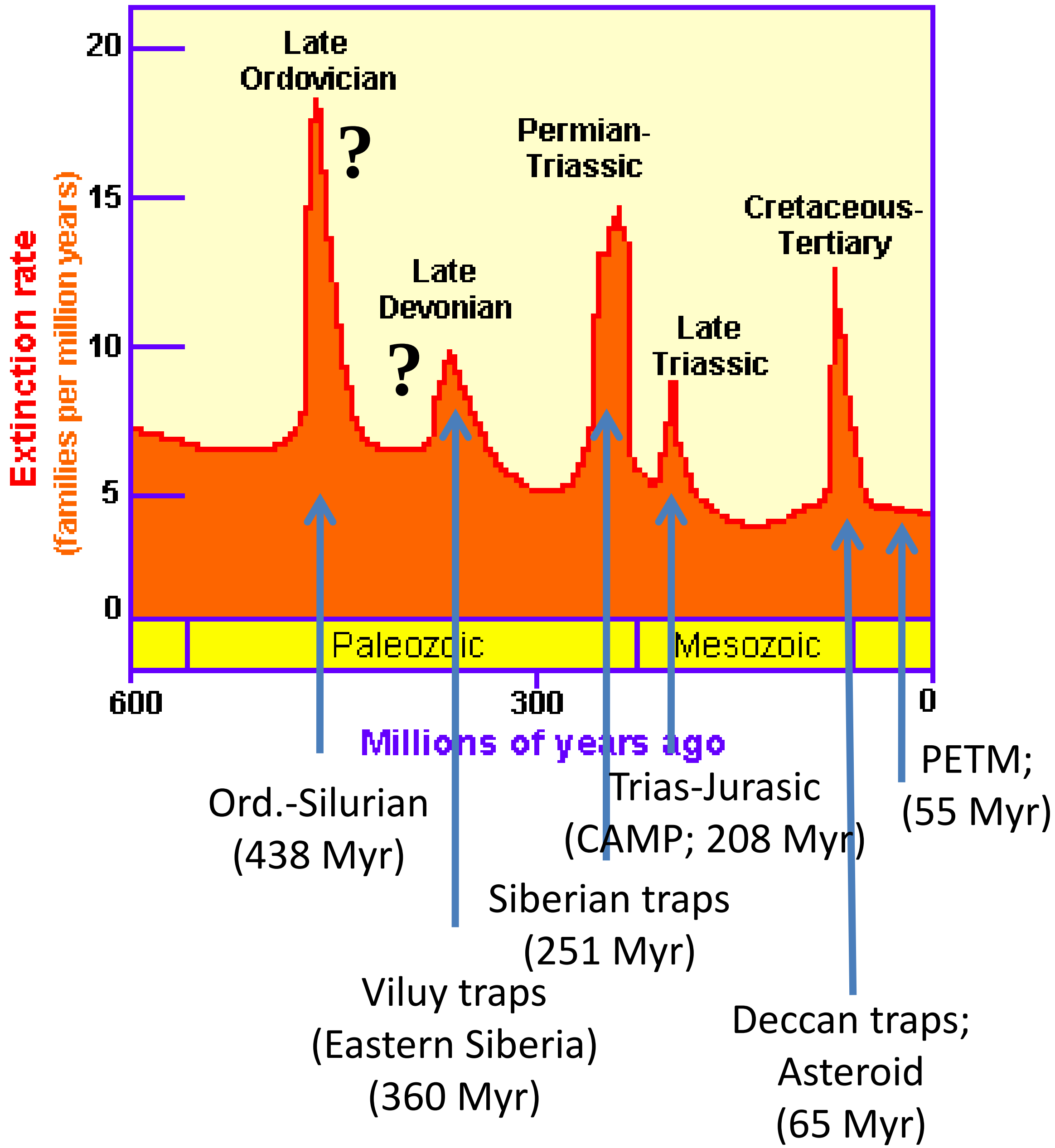


Oceans are Acidifying Fast ……….



It is happening now, at a rate and to a level not experienced by marine organisms for ~ 20MY

Turley et al. 2006



After Raup and Sepkoski
(www.enchantedlearning.com)

Carbon pertubation (Veron, 2008)

symtoms:

- Global warming
- Ocean acidification
- Anoxia

Important:

- Magnitude
- Rate of change

Response of marine biota to OA and climate change

- Strong perturbation at a very fast rate → K/T impact (major planktonic extinction)

Response of marine biota to OA and climate change

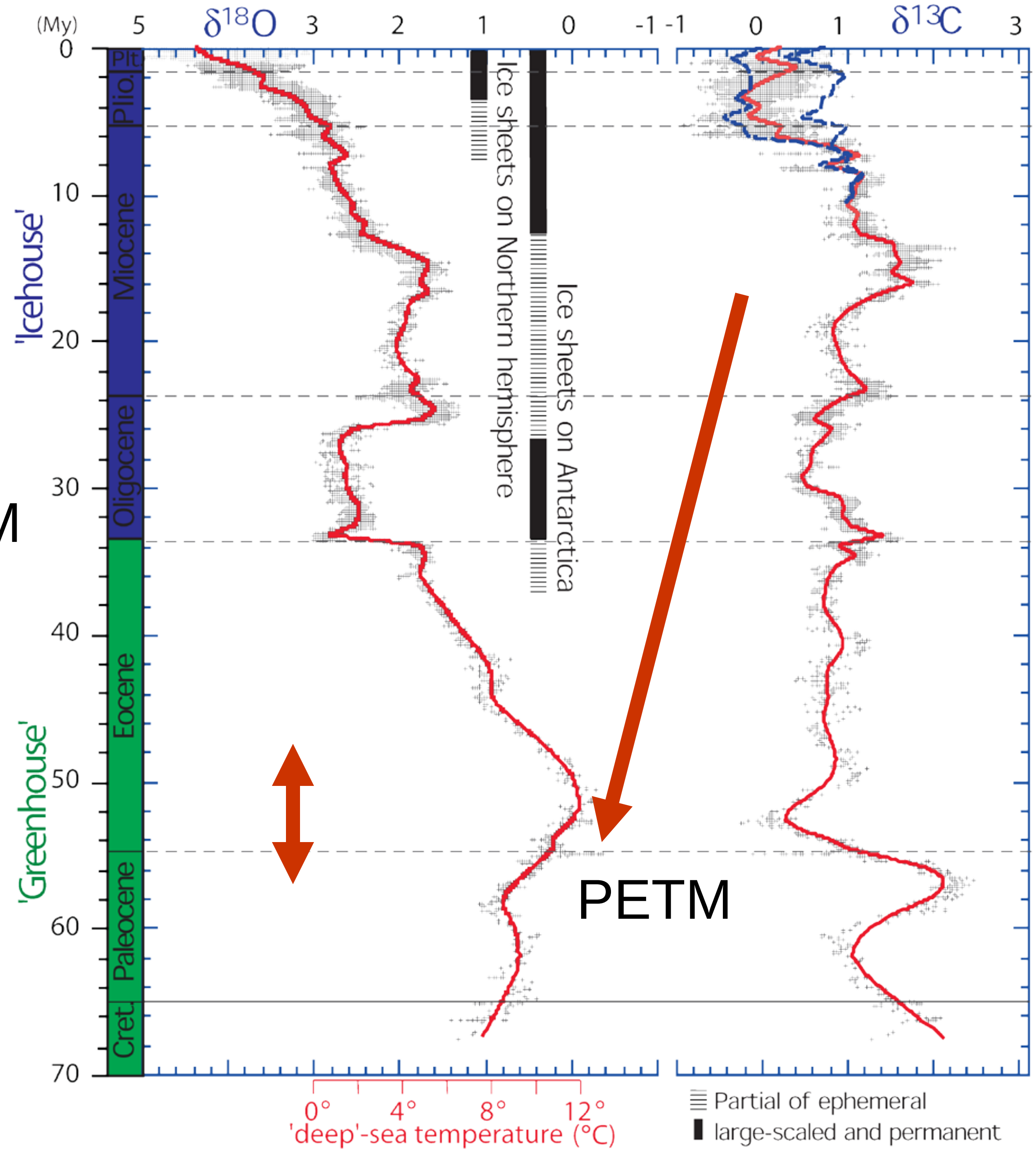
- Strong perturbation at a fast rate → K/T impact (major planktonic extinction)

- Strong perturbation at a „moderate“ rate → PETM (major benthic extinction)

Cenozoic
long-term trends

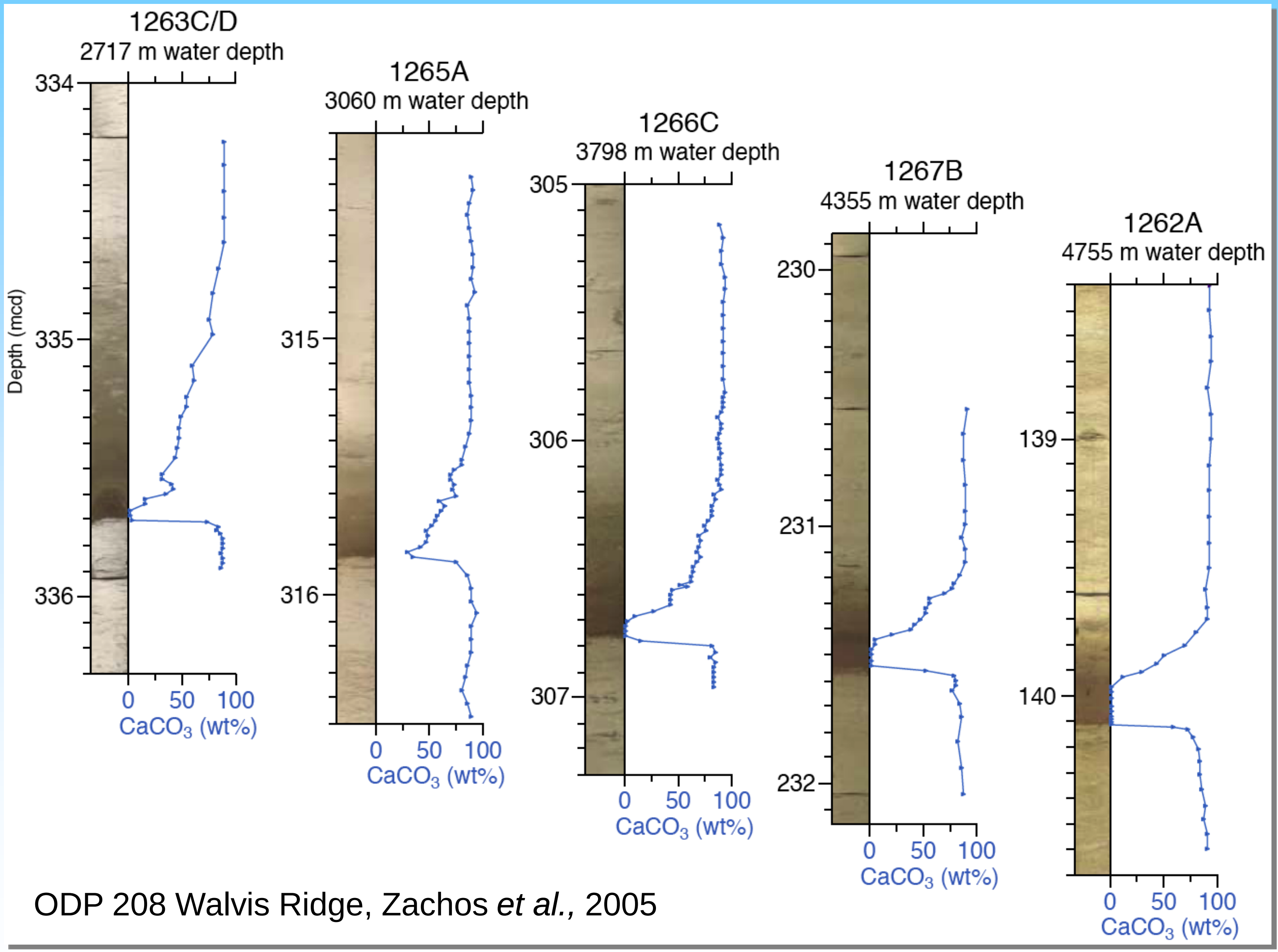
Early Eocene: warm
superimposed: PETM

One of the largest
benthic mass
Extinction in Earth
history



Zachos et al., 2001

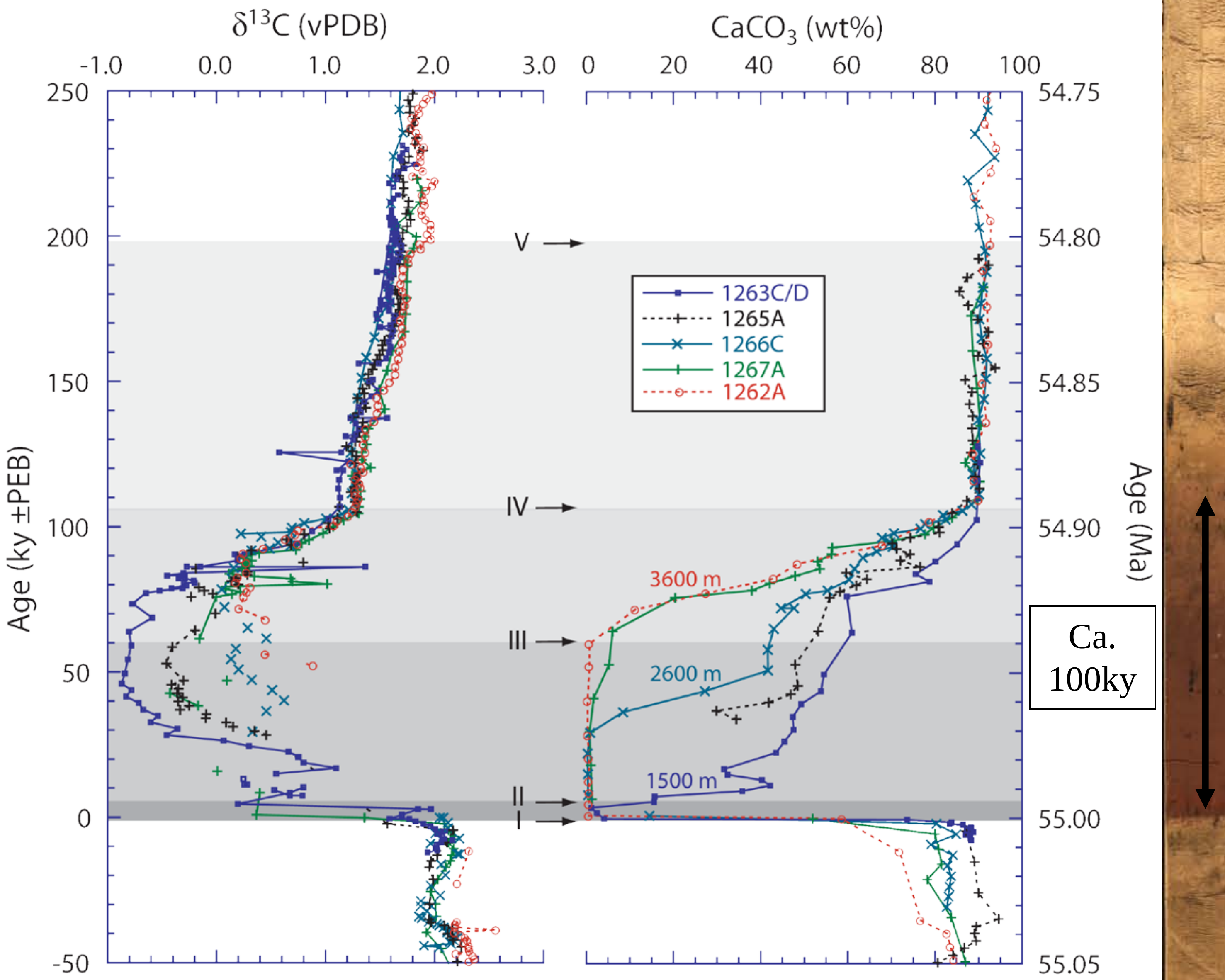
Ocean Carbonate; Walvis Ridge ODP Leg 208



ODP 208 Walvis Ridge, Zachos *et al.*, 2005

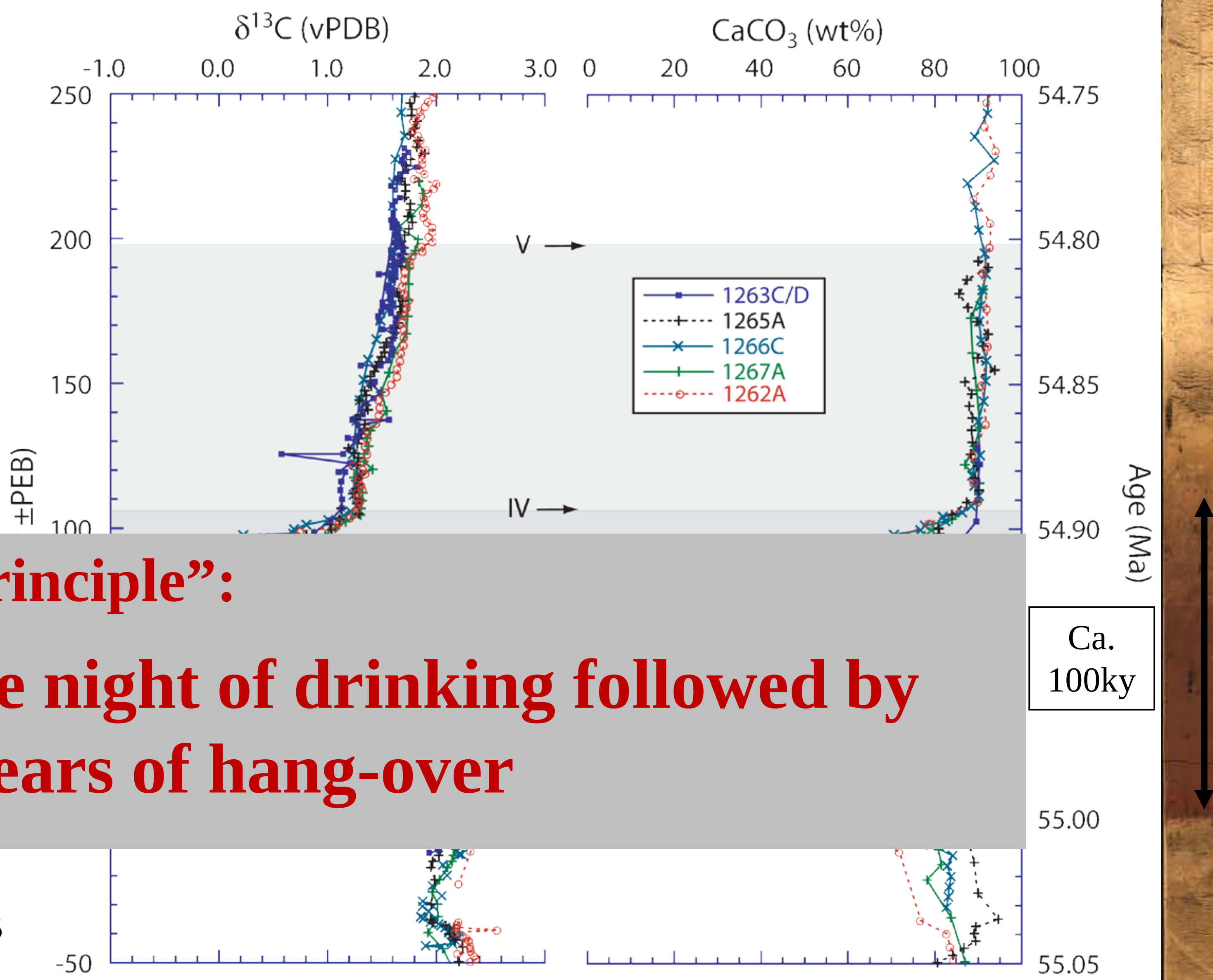
„Carbonate compensation“: as lysocline is rising it destroys benthic habitats

Oceanic recovery. Walvis Ridge ODP Leg 208



Zachos et al., Science 2005

Oceanic recovery. Walvis Ridge ODP Leg 208



"Sake principle":

One night of drinking followed by 2 years of hang-over

Zachos et al., Science 2005

Response of marine biota to OA and climate change

- Strong perturbation at a very fast rate → K/T impact (major planktonic extinction)
- Strong perturbation at a „moderate“ rate → PETM (major benthic extinction)
- Small perturbation at a slow rate → Neogene, G-IG (acclimation/adaptation)

Geochemistry Geophysics Geosystems G3
AN ELECTRONIC JOURNAL OF THE EARTH SCIENCES
Published by AGU and the Geochemical Society

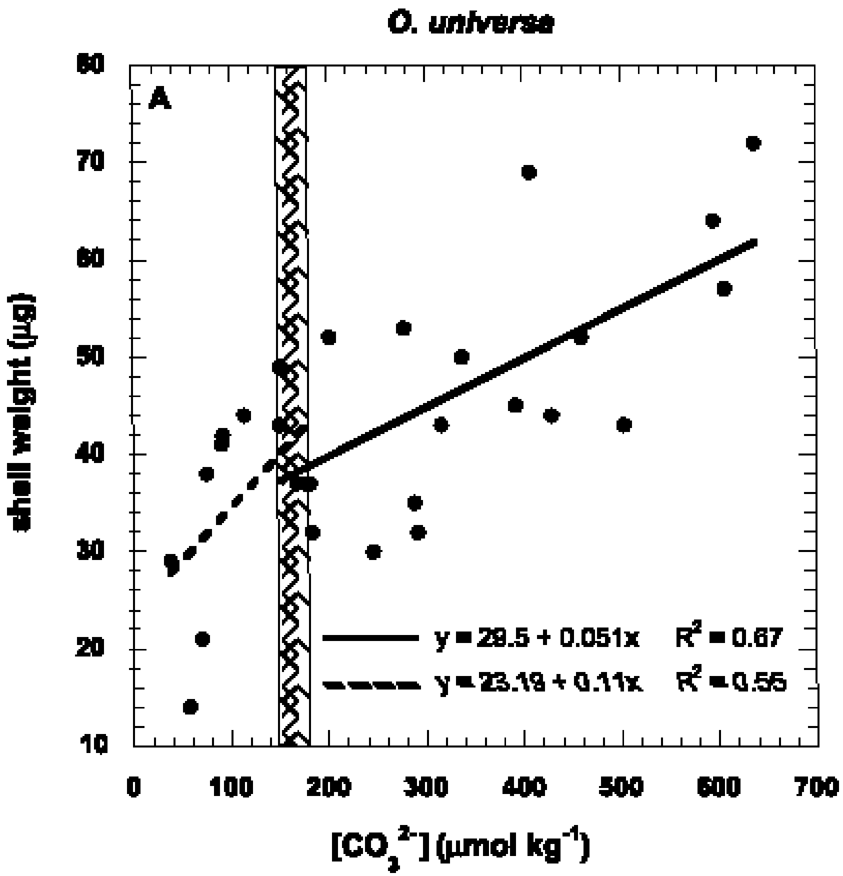
Comment
Volume 3, Number 11
8 November 2002
1064, doi:10.1029/2002GC000388
ISSN: 1525-2027

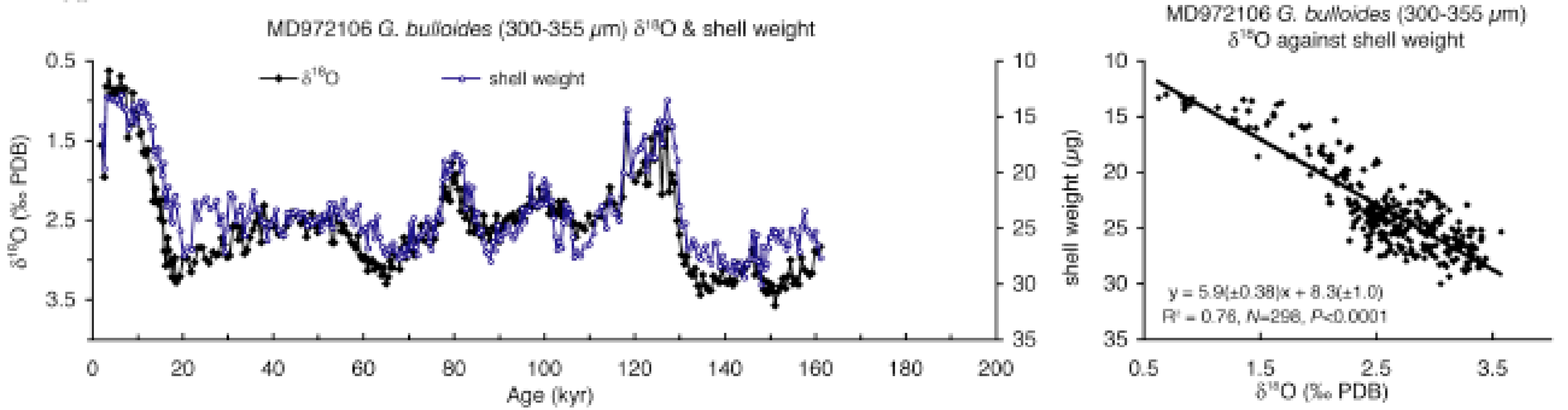
Impact of the ocean carbonate chemistry on living foraminiferal shell weight: Comment on "Carbonate ion concentration in glacial-age deep waters of the Caribbean Sea" by W. S. Broecker and E. Clark

Jelle Bijma, Bärbel Hönisch, and Richard E. Zeebe
Alfred Wegener Institute, Am Handelshafen 12, Bremerhaven, D-27570, Germany
(jbijma@awi-bremerhaven.de; bhoenisch@awi-bremerhaven.de; rzeebe@awi-bremerhaven.de)

$\Delta[CO_3^{2-}]_{G\text{-}IG} \rightarrow 100\mu mol\ kg^{-1}$

ca. 15% shell weight change

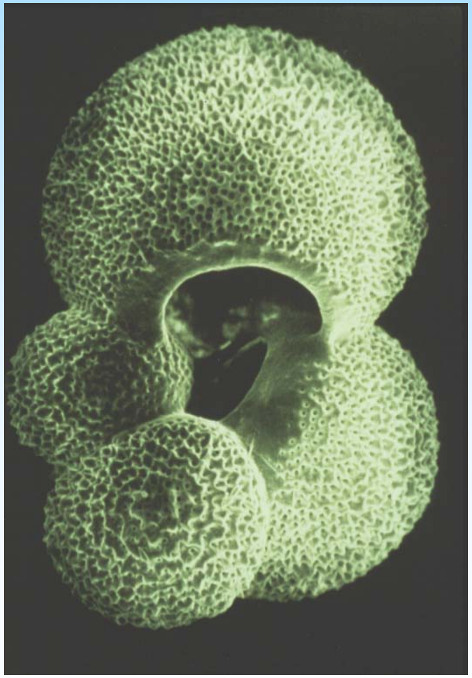




Moy, 2005

$\Delta[CO_3^{2-}]_{G\text{-}IG} \rightarrow 100\mu mol\ kg^{-1}$

ca. 50% shell weight change!



Globigerina bulloides

Response of marine biota to OA and climate change

- Strong perturbation at a very fast rate → K/T impact (major planktonic extinction)
- Strong perturbation at a „moderate“ rate → PETM (major benthic extinction)
- Small perturbation at a slow rate → Neogene, G-IG (acclimation/adaptation)
- Strong perturb. at a fast rate → Anthropocene: decrease in species richness → breakdown of ecosystems → extinction?

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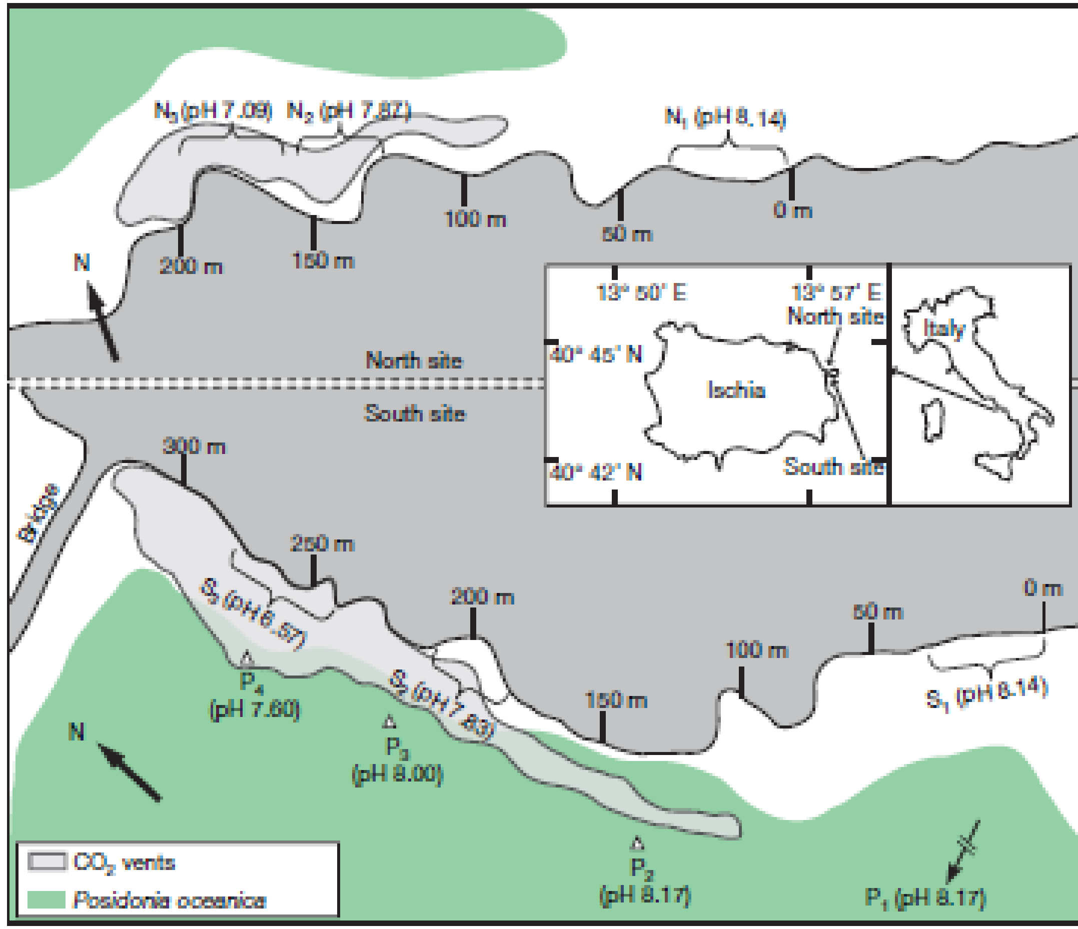
CO_2 Vents: "Windows" into High CO_2 Ocean to Assess Ecosystem Impacts



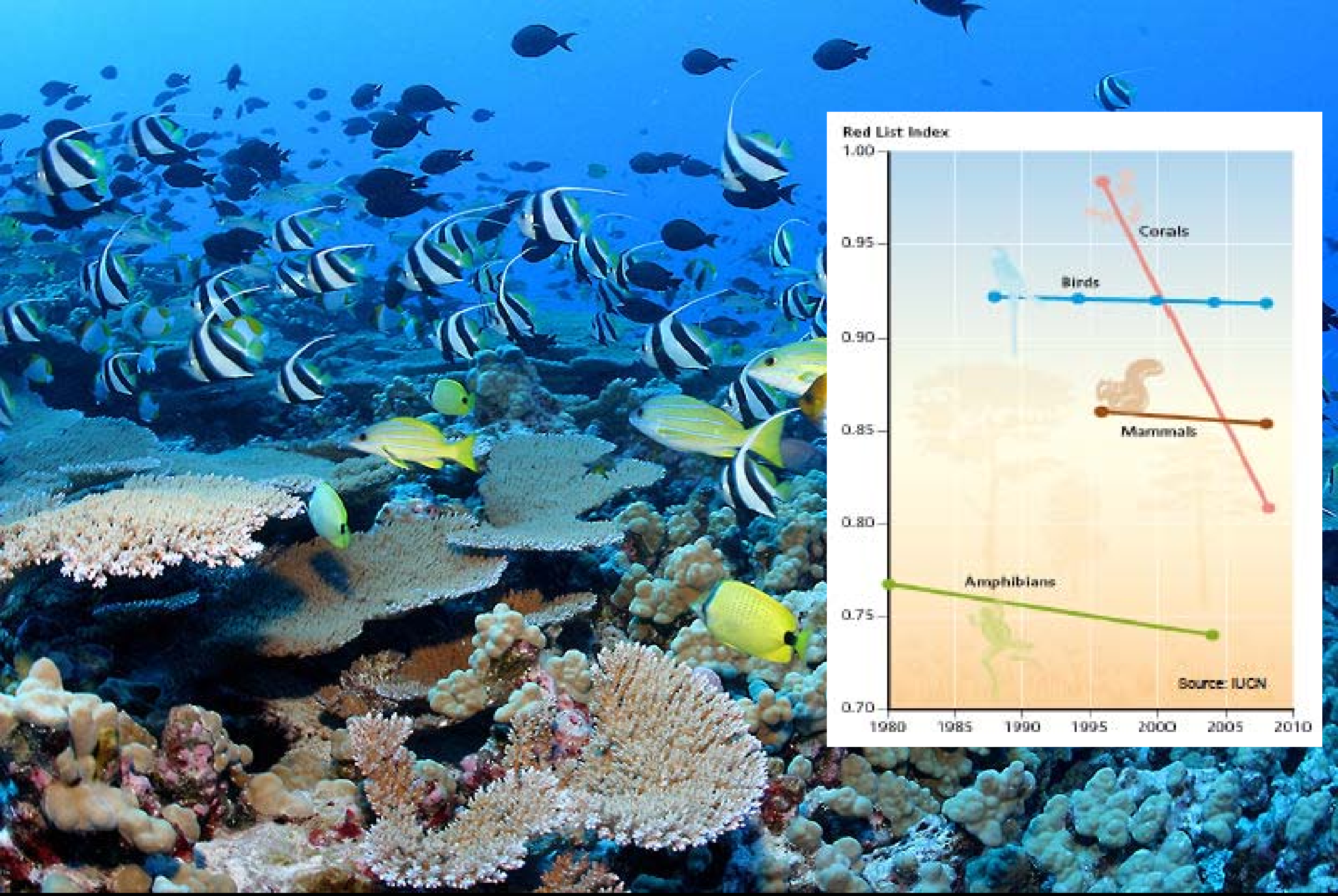
CO_2 Vents: "Windows" into High CO_2 Ocean to Assess Ecosystem Impacts

Hall-Spencer et al. Nature (2008)

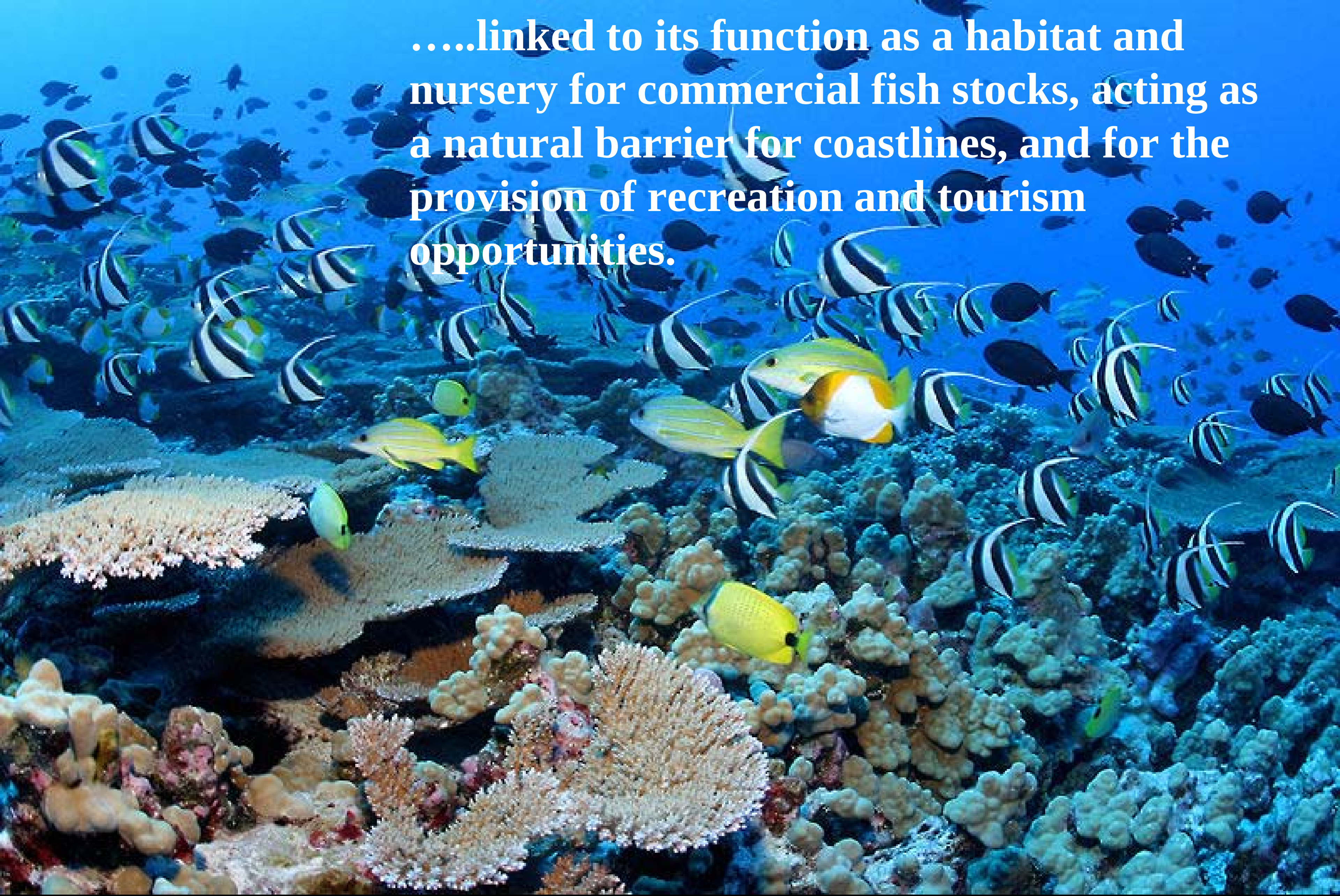
Studies in the shallow waters of the Mediterranean and deep-sea show:

- **total loss of some calcareous species**
- **reduced biodiversity**
- **"regime shifts": totally different ecosystems**

e.g. Sea grass benefit but so do invasive species

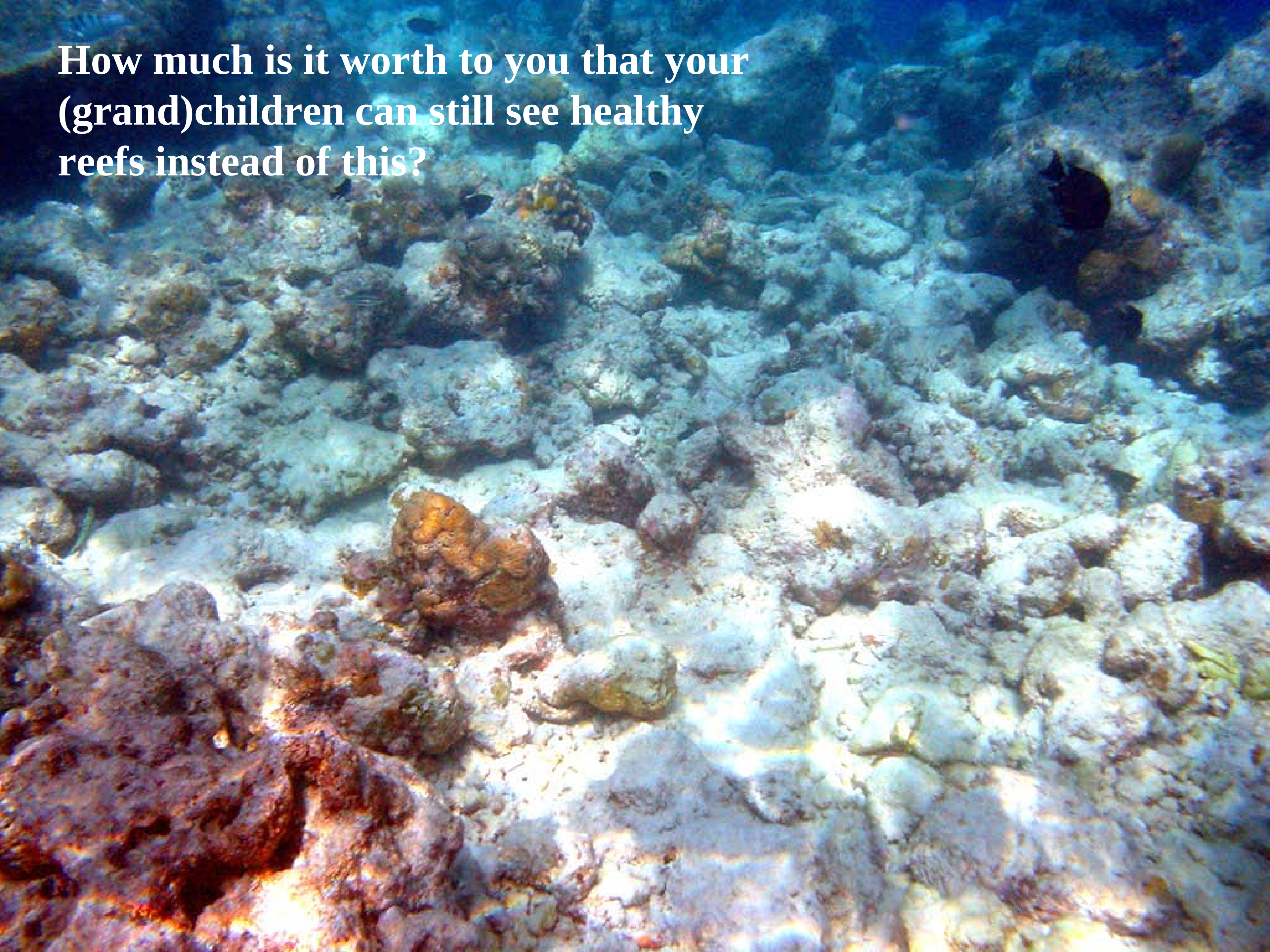

Red List Index
1.00
0.95
0.90
0.85
0.80
0.75
0.70
1980
1985
1990
1995
2000
2005
2010
Corals
Birds
Mammals
Amphibians
Source: IUCN

…..linked to its function as a habitat and nursery for commercial fish stocks, acting as a natural barrier for coastlines, and for the provision of recreation and tourism opportunities.



The global economic value associated with reefs is in the order of \$30 billion yr^{-1}. (Burke and Maidens, 2004)

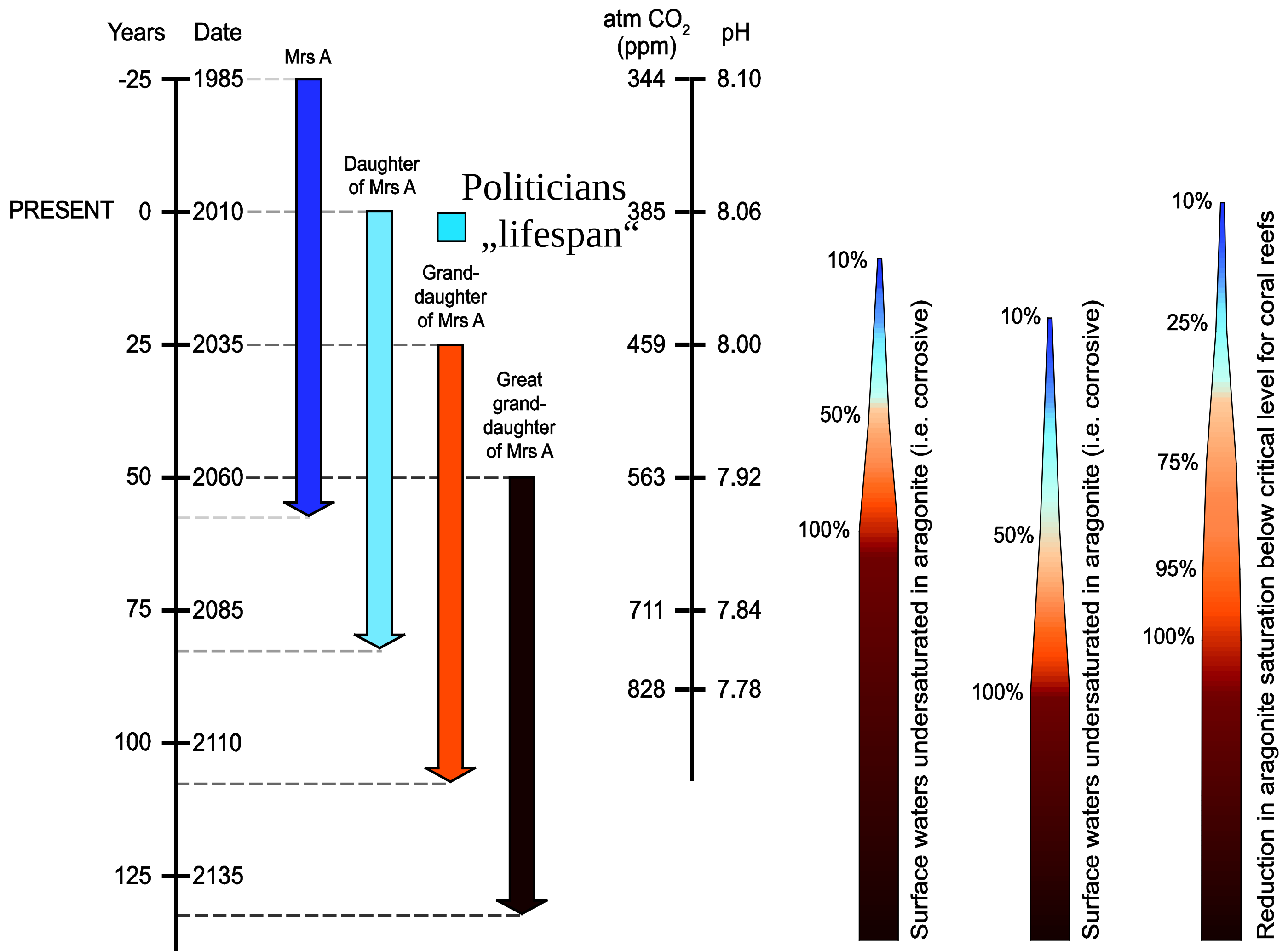

„…..cultural, moral, emotional value……..…“


How much is it worth to you that your (grand)children can still see healthy reefs instead of this?

Conclusions

- Ocean acidification is ongoing and future changes are very well predictable
- Organismal response – knowledge is growing (mostly calcifiers)
- Ecosystem response – difficult to answer but mesocosm experiments have started
- Evolutionary capability – completely unknown
- No perfect analogue to the present – rate of change is unprecedented
- Earth history tells us that the combination of OA, global warming and anoxia is a deadly mix

Potential Vulnerabilities in Relation to Human Life spans



Turley and Boot (in press) OUP Book on Ocean Acidification (Gattuso and Hansson


THERE
IS NO
PLANET B
Thank you for your attention