Acidification de l'océan et son impact sur les organismes et écosystèmes marins

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Une thématique de recherche récente

news

Researchers seek to turn the tide on problem of acid seas

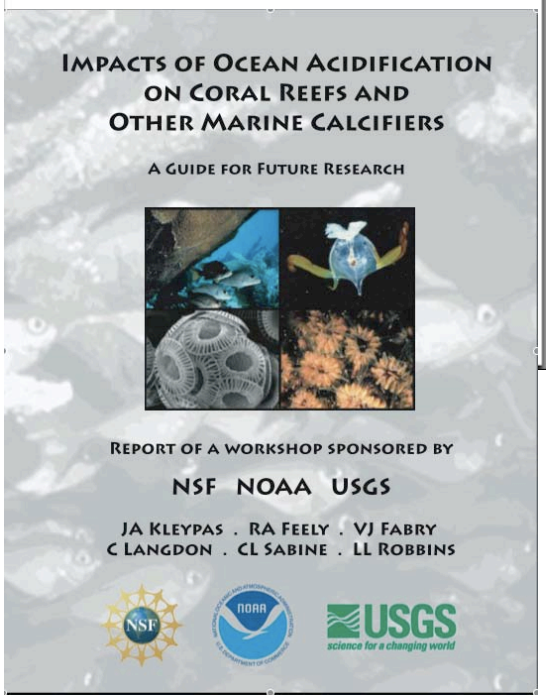
Quirin Schiermeier, Munich

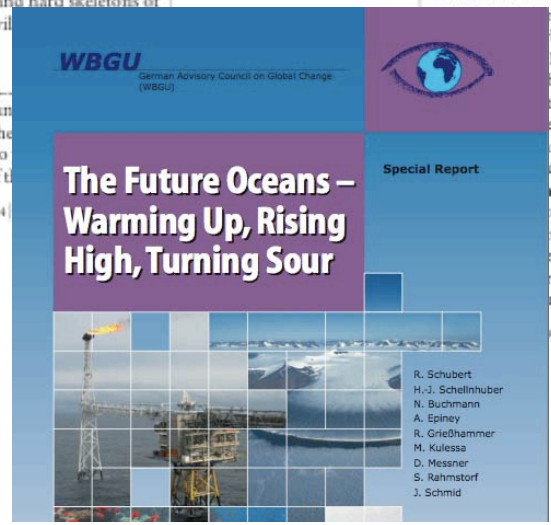
Researchers met last week to map out plans to study a serious but largely neglected

marine organisms will play a prominent part in the research plan. Last month, researchers showed that the shells and hard skeletons of

THE ROYAL SOCIETY

Ocean acidification due to increasing atmospheric carbon dioxide





news

Ocean fix for climate change finds tentative support

Jim Giles

Marine organisms can sense and avoid high concentrations of carbon dioxide, according to a study of a seafloor vent off the coast of Hawaii. The result provides tentative

…s to tackle climate change …bon dioxide in the ocean. …have long been concerned …n concentrations of CO_2 to …cause serious damage to … — some studies have …n kill marine organisms …des (see *Nature* 430, 391; …mentalists have blocked some …t further tests, fearing that …tions of CO_2 might open the …sts or industrial projects. …chers turned instead to …ral plume of CO_2 that bubbles up from a subsea volcano called Loihi, near Hawaii. They wanted to assess fears that adding CO_2 to the ocean might create a 'mortality sink' — a spot where marine organisms die, attracting scavenging creatures that would in turn be killed.

But this kind of death trap is unlikely to occur, says Jeffrey Summers, a physicist with the Office of Fossil Energy at the US energy department in Washington DC. Summers and colleagues set cages baited with mackerel close to the Loihi plume and at various distances from the CO_2. The bait away from the plume was eaten in less than 24 hours, whereas the bait over the vent remained untouched for more than a week.

Eric Vetter, a marine biologist at Hawaii Pacific University who worked with Summers on the project, thinks animals are avoiding the cages because they can sense the high CO_2 levels. "The results are promising," he says.

The study, scheduled to be presented on 6 September at the 7th International Conference on Greenhouse Gas Control Technologies in Vancouver, Canada, also suggests that sea creatures can recover from short blasts of CO_2. Summers' team dragged cages of amphipods — shrimp-like creatures — over the vent. The animals seemed to be anaesthetized by the gas within 10 minutes, but became active again around half an hour after being removed from the plume.

Vetter stresses that the work is "very preliminary", and adds that much more data are needed before conclusions can be drawn about the wisdom of dumping CO_2 in the sea. ■

…SEPTEMBER 2004 | www.nature.com/nature 115

…Nature Publishing Group

OCEAN SCIENCE

The Fate of Industrial Carbon Dioxide

Taro Takahashi

The atmospheric CO_2 conc… has increased from about 2… per million (ppm) in 1800–… ginning of the industrial age—to … today (*1*). During this time, the … annual rate of increase has been ab… of that expected from the estimate… trial CO_2 e… rate into th… sphere. This… that an am… CO_2 equiva…

Enhanced online at www.sciencemag.org/cgi/content/full/305/5682/352

352

concentration and the original oxygen co… centration, which in turn is obtained by a… suming saturation with the atmosphere … the temperature of water. The amount … $CaCO_3$ dissolution is estimated from t… difference between the observed alkalini… value and the original at-surface (or pre-… formed) value that is estimated as a fun… tion of salinity, phosphate, and oxyg…

NATURE | VOL 430 | 22 JULY 2004 | www.nature.com/nature

news

Project probes impact of waste carbon dioxide on marine life

David Cyranoski, Tokyo

Japanese researchers are beginning to make public the first data from a project that could allow waste carbon dioxide to be dumped in the ocean. The tests are aimed at finding what concentrations of …

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now

28 September 2005

Ocean Acidification Bad for Shells and Reefs

Rising levels of atmospheric carbon due to fossil fuel emissions have made seawater

Une thématique de recherche récente

Le Soir Mardi 3 avril 2007

La science du climat

« On transforme l'océan en Coca-Cola ! »

LE RAPPORT DU GIEC affine les impacts de l'augmentation des concentrations de CO_2 dans l'atmosphère. Etat de la question avec le climatologue belge Jean-Pascal van Ypersele.

ENTRETIEN

Professeur en climatologie à l'Université catholique de Louvain, Jean-Pascal van Ypersele est également vice-président du groupe II du Giec, consacré aux « impacts » et à l'« adaptation ».

Quelles sont les grandes différences entre ce rapport et celui de 2001 ?

Il n'y a pas énormément de différences. (…)Sur le réchauffement, on sait l'essentiel depuis 20 ans, pour ne pas dire 30. Le cœur du problème était déjà là, pour ceux qui voulaient bien en prendre connaissance. L'évidence est aujourd'hui plus précise, plus largement disponible et disposed'une couverture géographique plus vaste.

Le rapport comporte des originalités, notamment sur l'objectif ultime de stabiliser les émissions de gaz à effet de serre de manière à éviter toute perturbation anthropique dangereuse du système climatique. Devrait-il y avoir une priorité entre les politiques de réduction d'émission et l'adaptation ?

« L'immense majorité des glaciers recule à cause des changements climatiques. Mais dans les régions où ils sont les réservoirs d'eau pour des villes entières (…) il n'y aura plus d'eau… sauf quand il pleut »

Les deux sont nécessaires. Anciennement, on n'abordait pas ces questions ensemble. Ici, nous faisons l'intégration des deux, sur les liens et les limites entre adaptation et la prévention. Un exemple : on peut très bien se protéger dans les pays développés contre une montée des mers de cinquante centimètres, mais cinq mètres, c'est autre chose. Économiquement d'abord, puis d'un point de vue de la population. Qui voudrait habiter derrière un mur haut de cinq mètres qui contient une mer ou un océan ? Les Hollandais ont travaillé sur cette question. Dans un tel cas, on ne peut qu'envisager la solution du terrifiant.

Le Giec constate que l'augmentation des concentrations de CO_2 aura un impact positif sur les rendements de l'agriculture dans le nord de l'Europe…

Oui, mais jusqu'à certain taux de concentration, ensuite la qualité risque ensuite de chuter. Mais bien sûr, pour l'agriculture, il faut aussi tenir compte des événements extrêmes. Il y a, à ce propos, beaucoup de discussions.

L'accès à l'eau ne devrait pas être menacé en Belgique. Ce qui n'est pas le cas de nombreux pays…

L'immense majorité des glaciers recule à cause des changements climatiques. Mais dans les régions où ils sont les réservoirs d'eau pour des villes entières se trouvant en contrebas, dans le voisinage, il n'y aura plus d'eau… sauf quand il pleut. Cela change tout. C'est dramatique. C'est le cas en Europe, dans les Andes, au Népal…

Que pensez-vous du scénario de l'arrêt du Gulf Stream et d'un refroidissement de l'Europe subit ?

C'est un des sujets qui m'énervent. (…) Le groupe II du Giec a dit très clairement ce qu'il en était. Ce risque est très faible pour l'Europe au XXIe siècle.

A l'opposé, le climat pourrait-il s'emballer si l'homme ne limite pas les émissions de gaz à effet de serre ?

Ce phénomène est également très peu probable. Il est intéressant d'en avoir connaissance. De grandes quantités de méthane gelées pourraient se relâcher en raison de l'effet de réchauffement. C'est important de la savoir en raison de la puissance vingt-cinq fois plus élevée par kilo de ce gaz relâché dans l'atmosphère par rapport au CO_2. Mais la Terre n'est pas sur Vénus, plus proche du Soleil que notre planète, et la position de notre atmosphère est différente…

Il y a déjà tellement de raisons de se trouver loin en dessous de ce seuil là, s'il existe, que la question de l'emballement du climat ne me semble pas être majeure.

L'acidification des océans, pointée du doigt pour la première fois, vous inquiète-t-elle davantage ?

Une série de facteurs d'amplification n'agissent pas forcément brutalement mais rendent le problème d'autant plus difficile à résoudre que l'on attend pour s'y attaquer.

Or, comme le note bien le rapport, l'océan se nature petit à petit en CO_2. C'est un problème majeur dont on va parler beaucoup dans les années qui viennent. Il faut savoir que l'on transforme la composition chimique de l'océan. On le transforme d'une certaine manière en Coca-Cola ! Et je ne pense pas que la vie marine puisse s'y développer aussi facilement que dans de l'eau normale.

Est-ce encore utile de produire trois rapports différents mais complémentaires tous les cinq ans. Le Giec ne nécessite-t-il pas d'être réformé ?

Peut-être. Une réflexion informelle a commencé à ce sujet. Rien ne dit que le prochain rapport du Giec, s'il y en a un, dans 5, 6, 7 ans, aura la même structure. Une approche plus intégrée que maintenant est nécessaire. Il y aura une certaine clarification de certains aspects grâce à l'interaction entre les scientifiques et les décideurs.

On parle de consensus scientifique sur les changements climatiques. Mais des scientifiques continuent à contester la thèse du réchauffement d'origine humaine. Les rapports du Giec en tiennent-ils compte ?

Le Giec fait de l'évaluation de la science et des connaissances scientifiques d'une manière très sérieuse. Prenons un peu

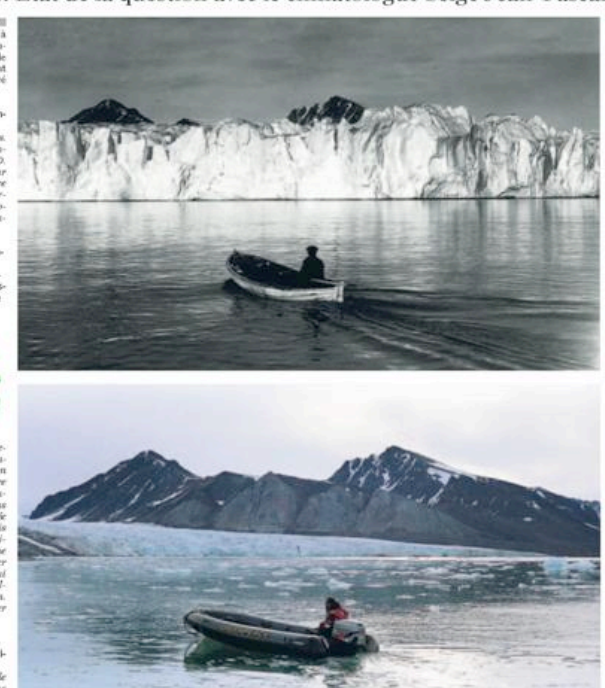
« Le processus du Giec est exhaustif, rigoureux et très lourd. Ses rapports ne sont donc pas manipulés comme on pourrait vouloir le laisser croire. Ils sont au contraire relativement conservateurs… »

de recul pour constater que ce processus totalement transparent est unique au monde. Dans le cas de ce rapport-ci, la table des matières a été adoptée en 2003. On a lancé un appel ouvert pendant trois mois pour solliciter des auteurs proposés par les gouvernements et désignés par le bureau du Giec en fonction de la qualité des curriculum vitae. (…) C'est très large. Le projet est ainsi nourri de milliers de commentaires dûment consignés. On sait d'où provient chaque commentaire et le sort qui lui est réservé. (…) Le processus du Giec est exhaustif, rigoureux et très lourd. Ses rapports ne sont donc pas manipulés comme on pourrait vouloir le laisser croire. Au contraire, ils sont relativement conservateurs… ■

propos recueillis par CHRISTIAN DUBRULLE ET CHRISTOPHE SCHOUNE

lesoir.be

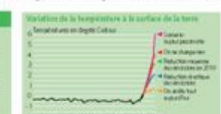
L'intégralité de l'interview est consultable sur http://blog.lesoir.be/empreinte-eco



LE GIEC PRÉVOIT la disparition de la plupart des petits glaciers, en Europe, d'ici à 2050. Situé dans la baie du Roi (Kongsfjorden), en Norvège, le glacier Blomstrandbreen a reculé d'environ deux kilomètres depuis 80 ans. PHOTOS AP

CONTROVERSE

C'est l'histoire d'une courbe de hockey (figure de droite) controversée. Etablissant un lien entre la concentration des émissions de carbone dans l'atmosphère et l'augmentation des températures, ce graphique utilisé en 2001 par le Giec a été expurgé du rapport 2007. Et pour cause, ces calculs (Mann, 1999) auraient omis la période chaude médiévale pour cause de sélection inappropriée des données (Mc Intyre, 2005). Un argument utilisé par les sceptiques pour contester l'origine humaine du réchauffement.



Chaud

La température moyenne du globe a gagné 0,7° depuis cent ans (2° en Belgique). Selon les scénarios, elle devrait encore augmenter de 1,8 à 4° d'ici à 2100. Les températures enregistrées entre décembre et février 2007 ont été les plus élevées jamais répertoriées à cette période de l'année, avec une température moyenne supérieure de 0,72°C à la moyenne du XXe siècle, selon l'administration américaine.

What is the cause of OA?

- CO_2 emissions:
  - 1990-1999 : +1% per year
  - 2000-2007 : +3.4% per year

Global Carbon Project

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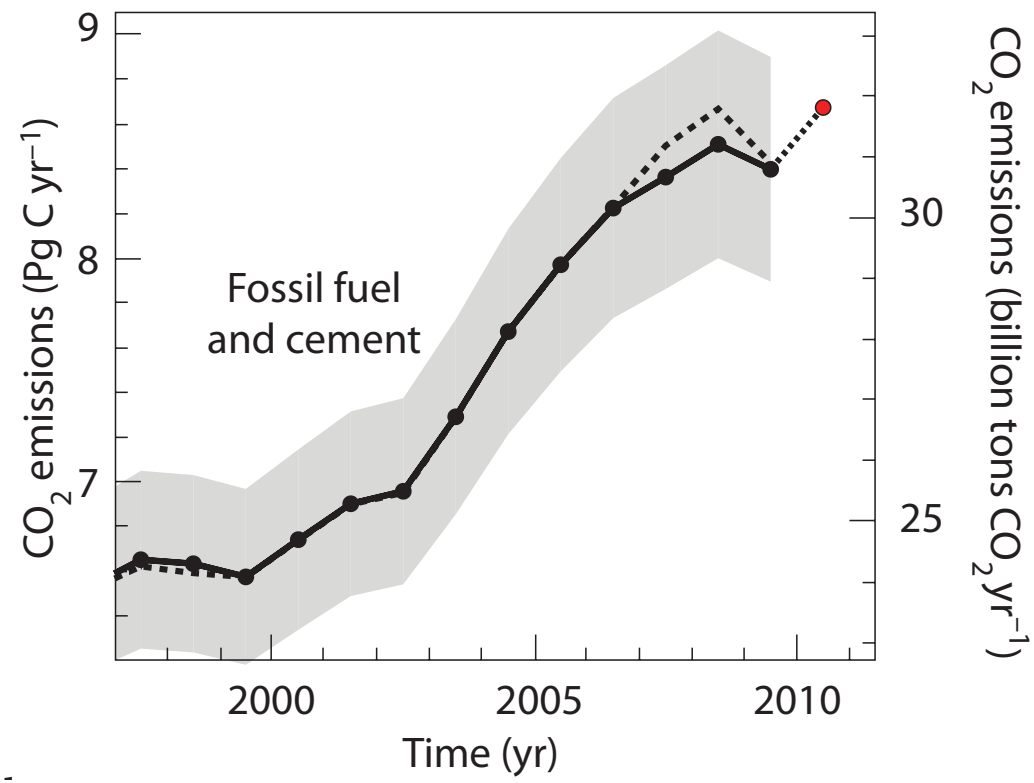


Global Carbon Project

2000-2007

1.4 Pg C y^{-1}

+

7.7 Pg C y^{-1}

9 billion
tons C y^{-1}

Le Quéré et al. (2009)

2000-2007

1.4 Pg C y^{-1}

+

7.7 Pg C y^{-1}

9 billion tons C y^{-1}

4.1 Pg y^{-1}

Atmosphere

45%

2.7 Pg y^{-1}

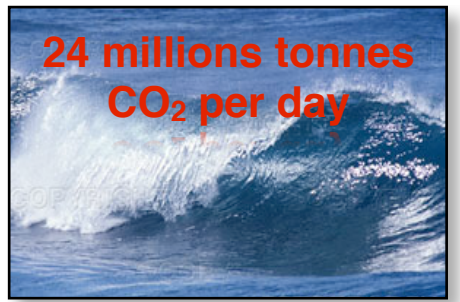
Vegetation

29%

2.3 Pg y^{-1}

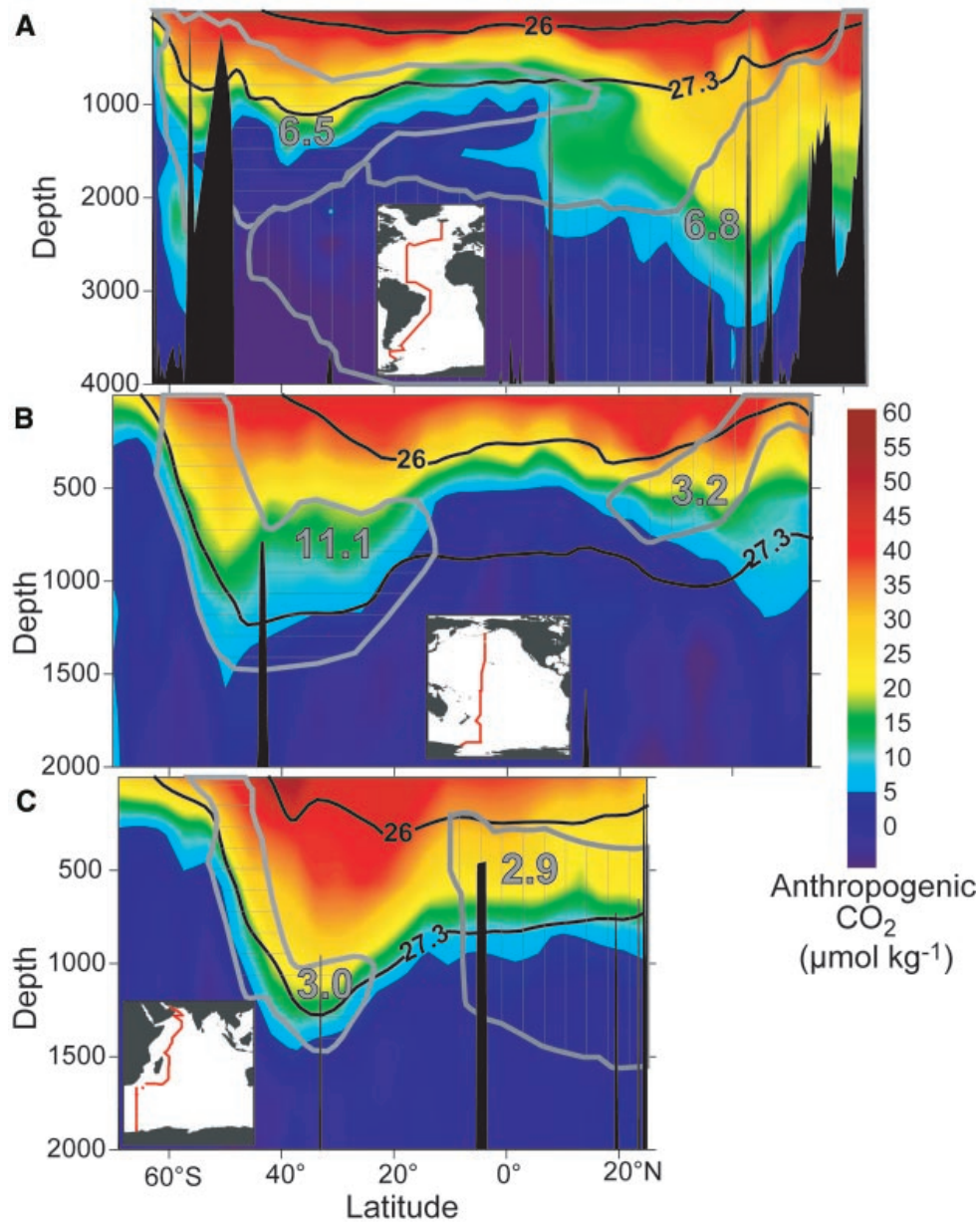
Oceans

26%



Le Quéré et al. (2009)

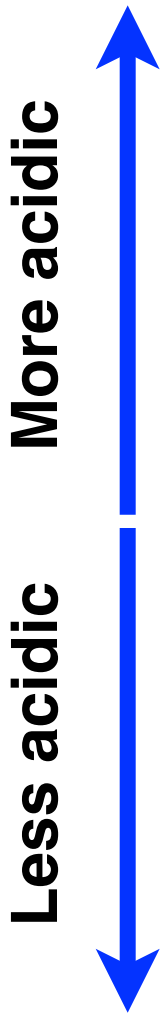
CO_2 invasion



Sabine et al. (2004)

Acidity and pH

- Logarithmic scale
- Like the Richter scale
- Decrease of pH from 8 to 7 = 10 times increase in acidity!



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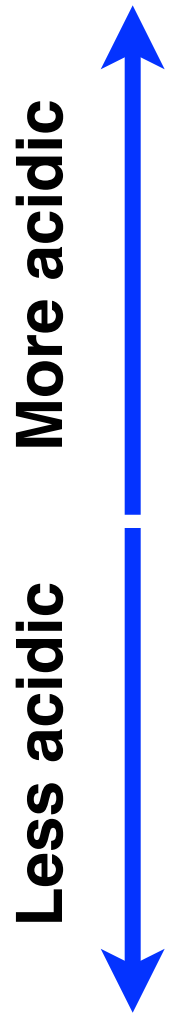

Concentrations of Hydrogen ions compared to distilled water (pH)		Examples of solutions and their respective pH
10,000,000	0	Battery Acid
1,000,000	1	Hydrochloric Acid
100,000	2	Lemon Juice, Vinegar
10,000	3	Orange Juice, Soda
1,000	4	Tomato Juice
100	5	Black Coffee, Acid Rain
10	6	Urine, Saliva
1	7	“Pure” Water
1/10	8	Sea Water
1/100	9	Baking Soda, Toothpaste
1/1,000	10	Milk of Magnesium
1/10,000	11	Household Ammonia
1/100,000	12	Soapy Water
1/1,000,000	13	Bleach, Oven Cleaner
1/10,000,000	14	Liquid Drain Cleaner

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Less acidic

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What is ocean acidification?

Increased CO_2

$$CO_2 + H_2O \rightarrow HCO_3^- + H^+$$

$$H^+ + CO_3^{2-} \rightarrow HCO_3^-$$

$$CO_2 + CO_3^{2-} + H_2O \rightarrow 2HCO_3^-$$

Decreased carbonate

Increased bicarbonate

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Decreased carbonate

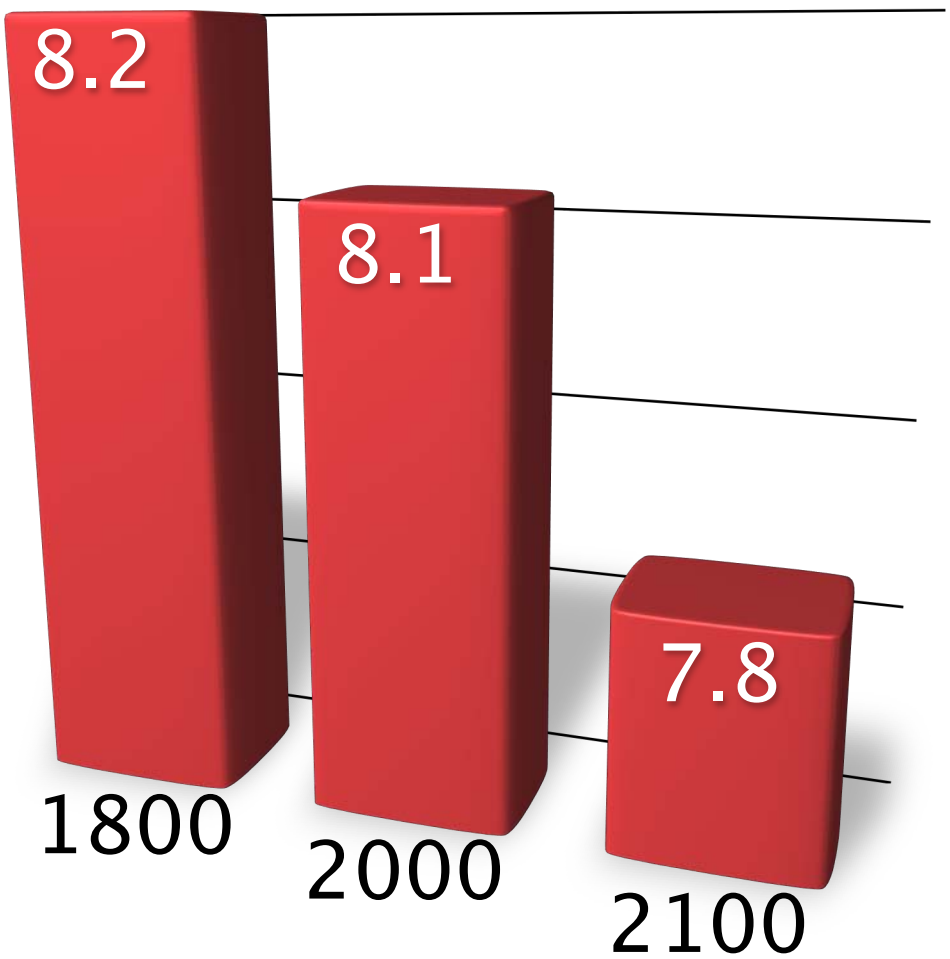
Increased bicarbonate

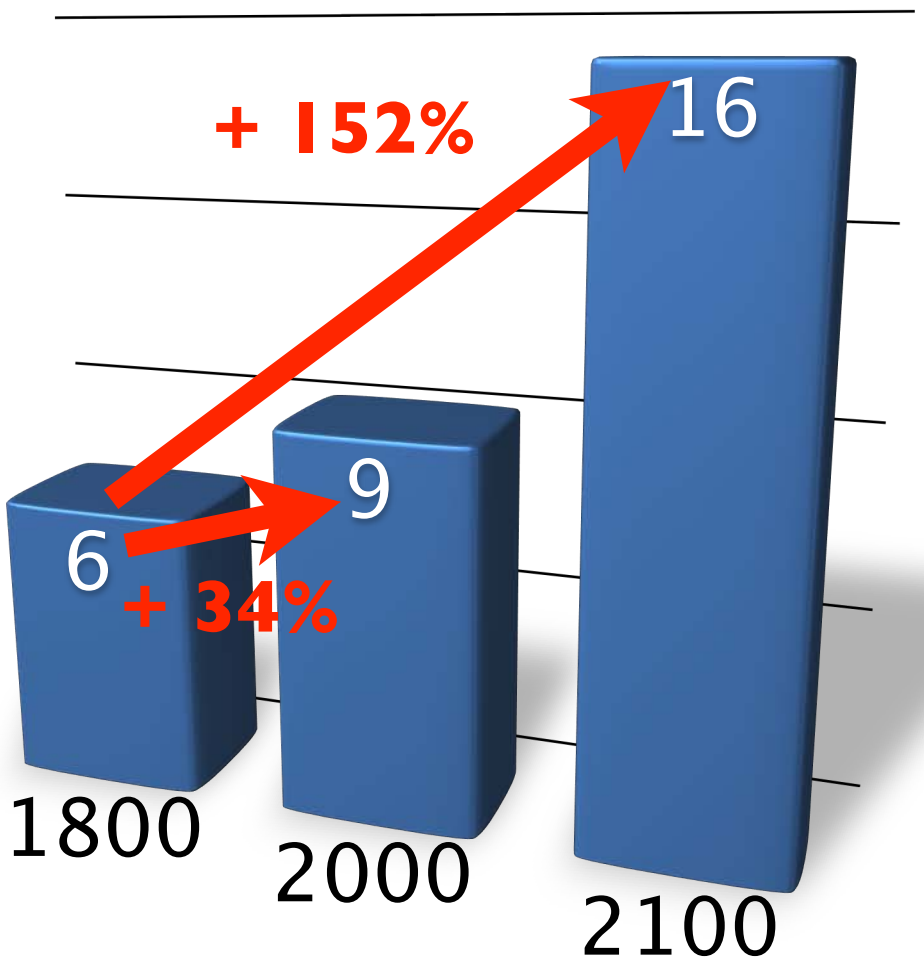
$$[H^+] = K_2^* \frac{[HCO_3^-]}{[CO_3^{2-}]}$$

Hydrogen ion concentration increases and pH decreases

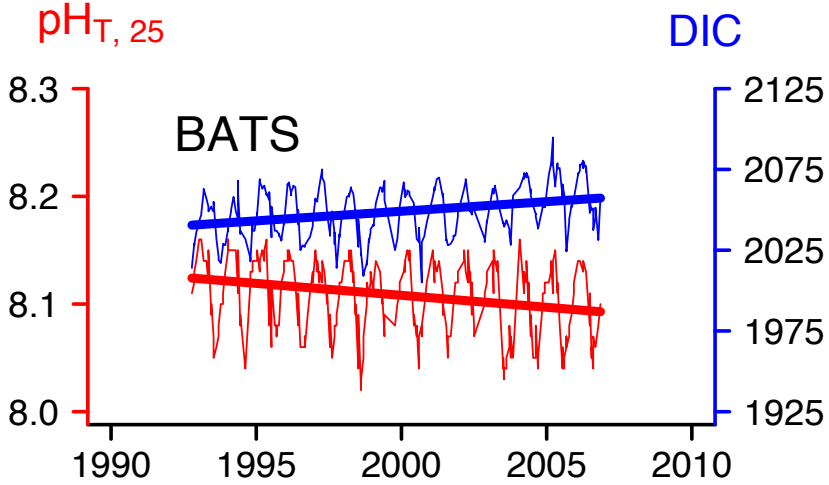
Acidity increases:
"*ocean acidification*"

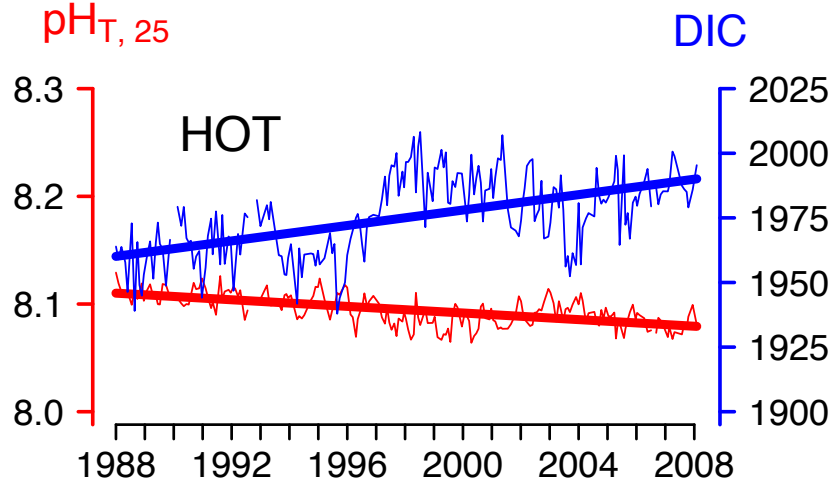
What is ocean acidification?

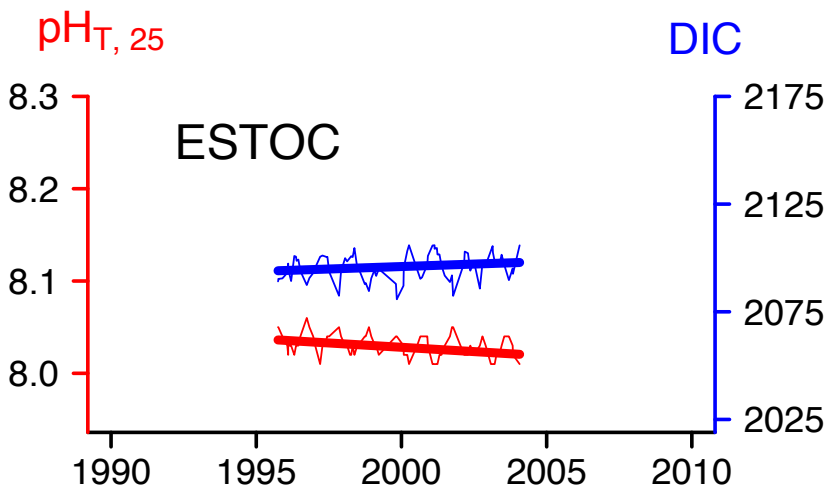


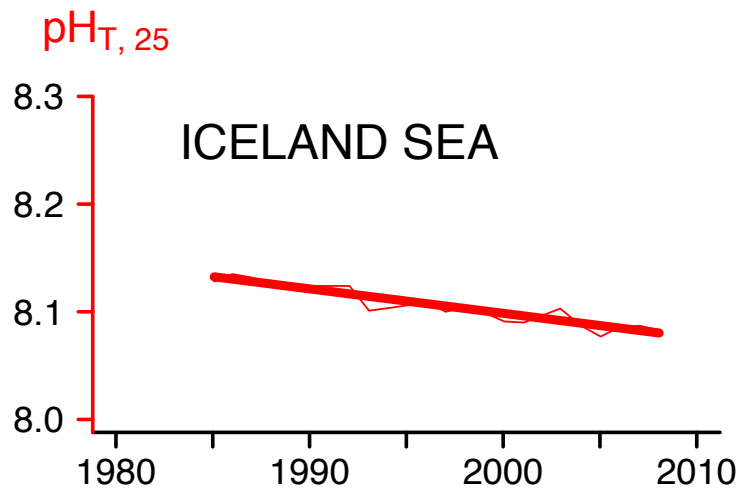


OA can be measured









Research projects

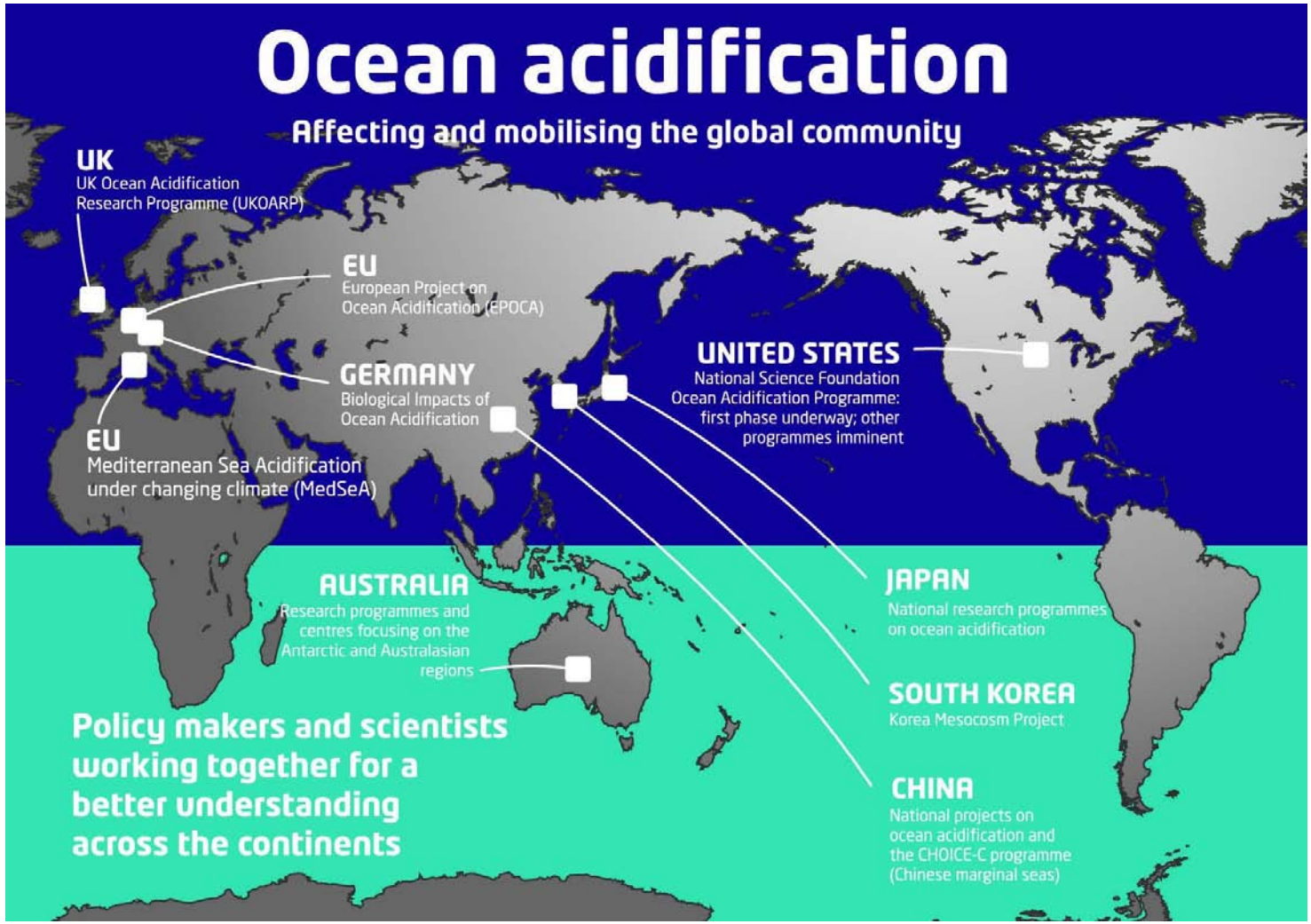
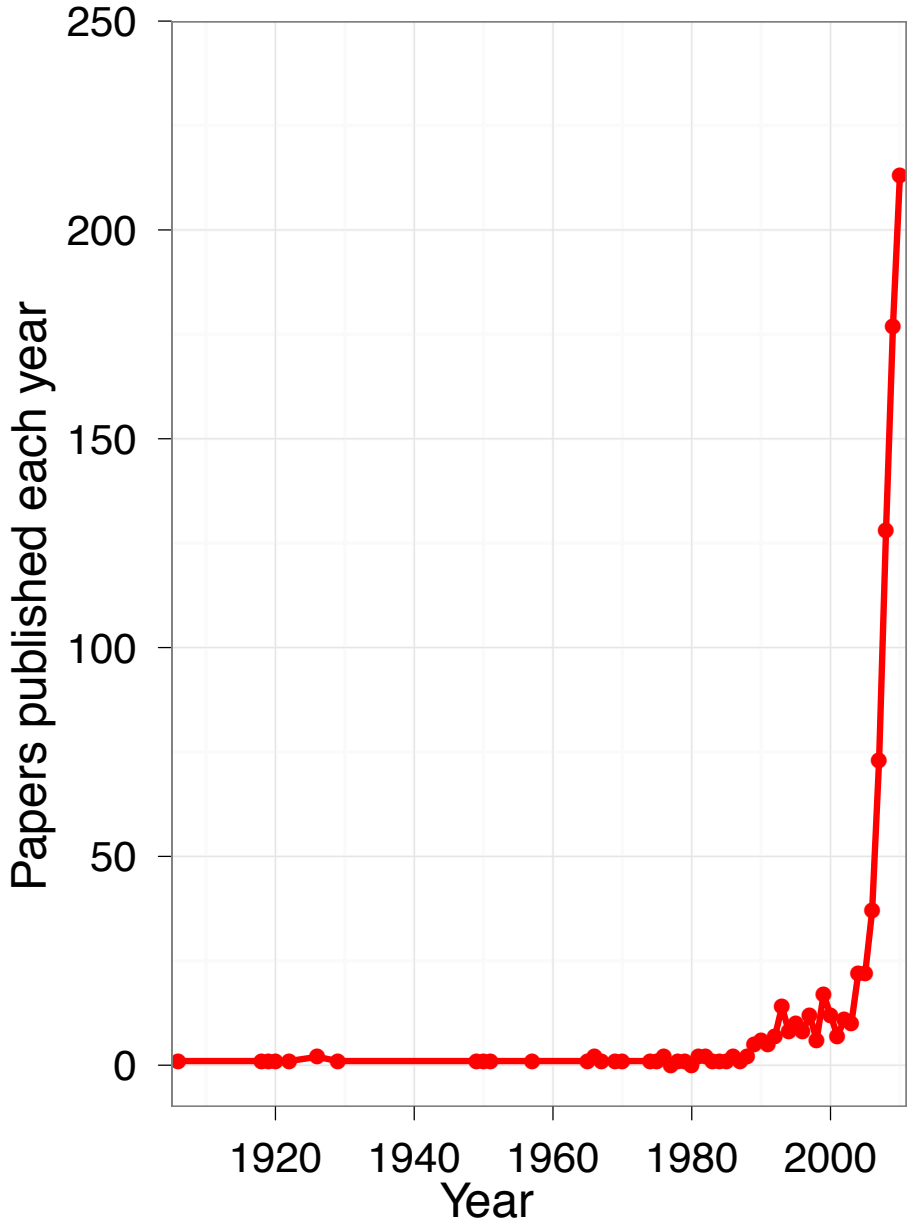
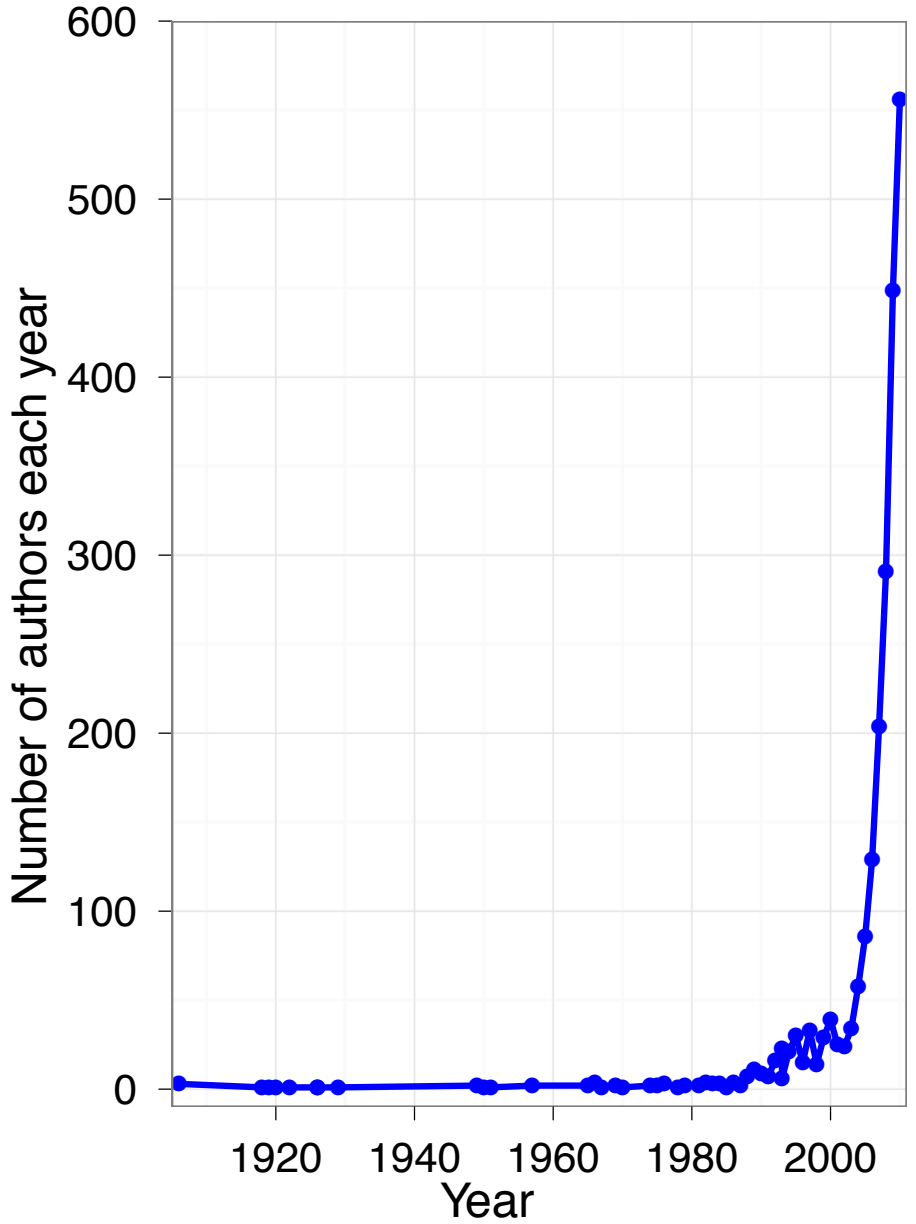


Figure 1: Major ocean acidification research programmes around the world in 2011 (Courtesy Keizer et al., PML).

Considerable increase in research efforts





Gattuso & Hansson (in press); Gattuso *et al.* (in press)

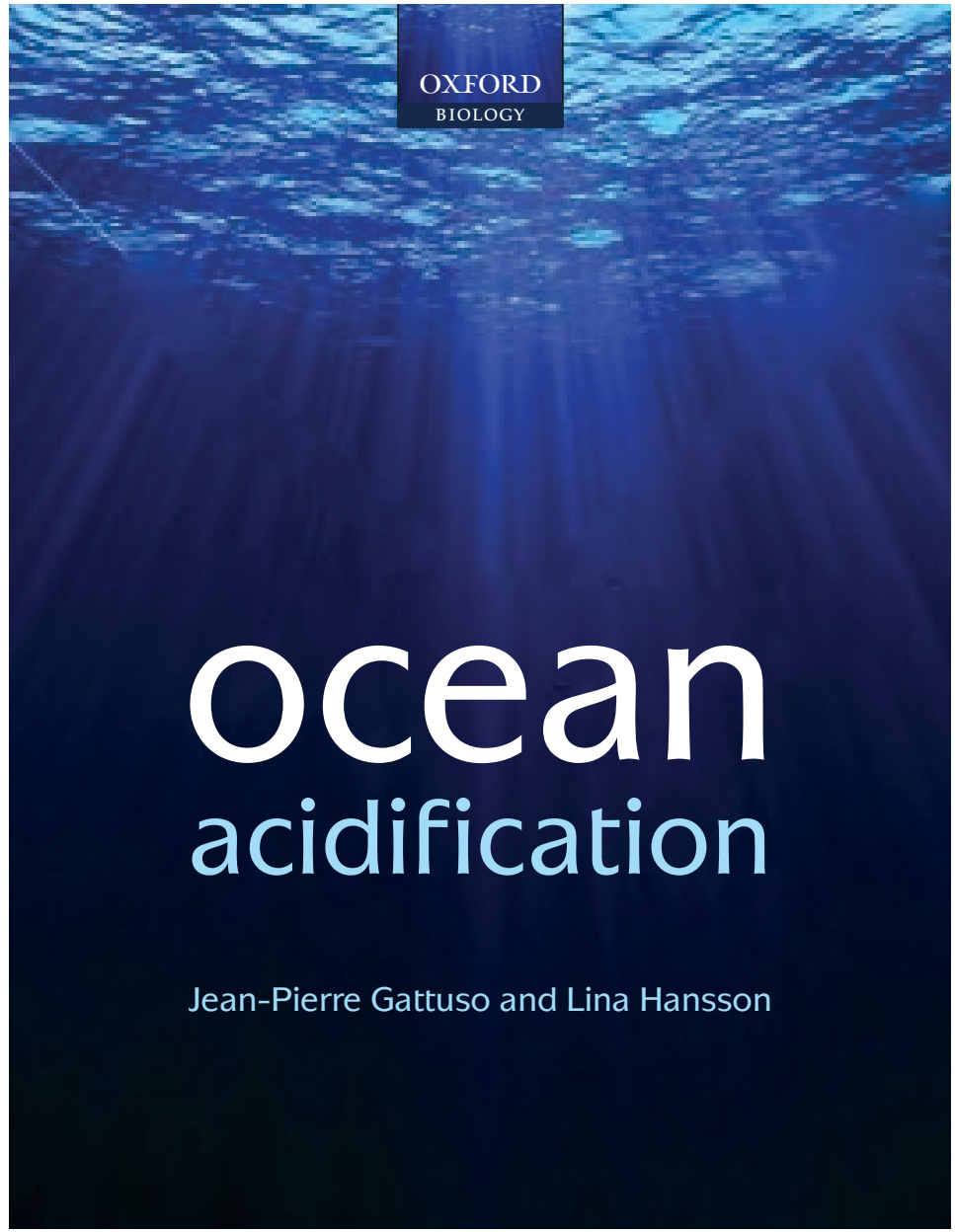
Biological response: meta-analyses

Biological response: meta-analyses

- **Hendriks & Duarte (2010)**: *... limited impact of experimental acidification on organism processes... except on calcification*
- **Kroeker et al. (2010)**: *... biological effects of ocean acidification are generally large and negative...*
- **Liu et al. (2010)**: *This review and analysis ... suggest that ... the rates of several (*microbial*) processes will be affected by ocean acidification, some positively* (N_2 fixation...)*, others negatively.*

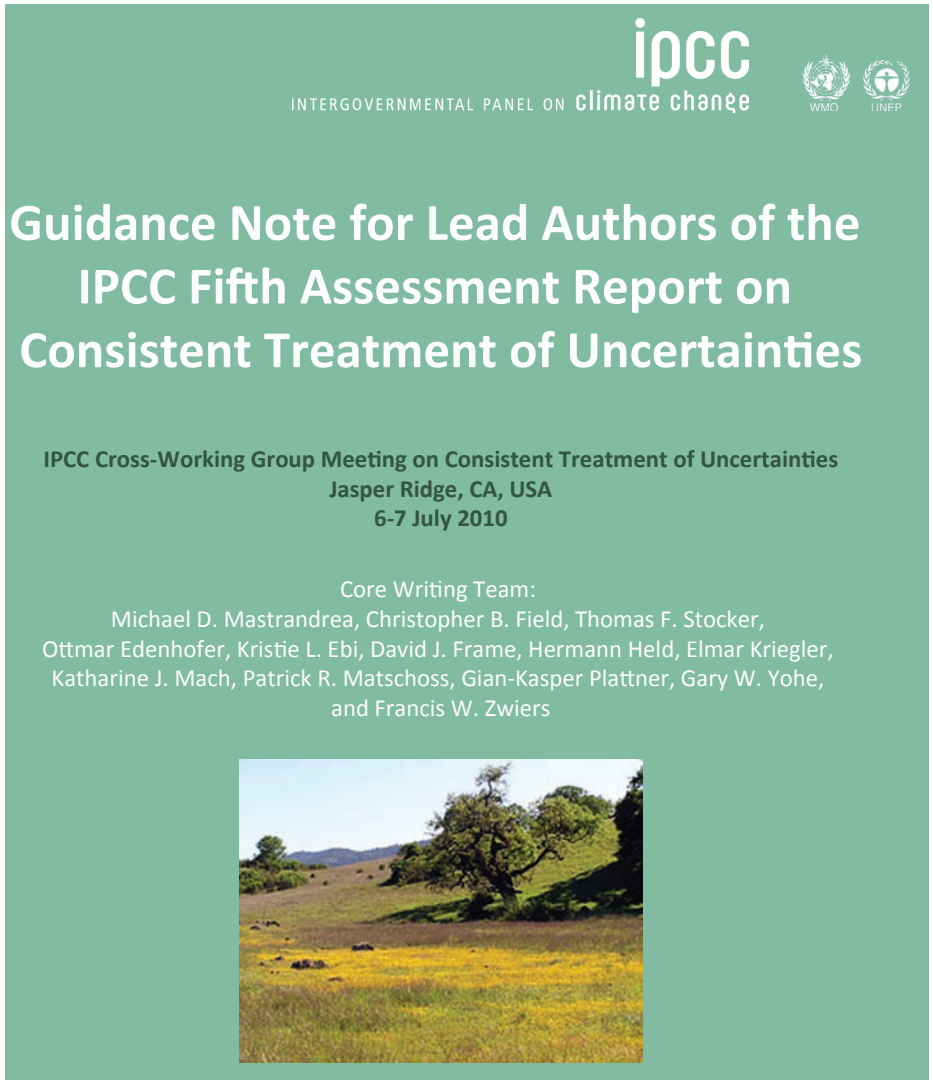
OA: knowns, unknowns and perspectives

1. Ocean acidification: background and history (Gattuso & Hansson)
2. Past changes of ocean carbonate chemistry (Zeebe & Ridgwell)
3. Recent and future changes in ocean carbonate chemistry (Orr)
4. Skeletons and ocean chemistry: the long view (Knoll & Fischer)
5. Effect of ocean acidification on the diversity and activity of heterotrophic marine microorganisms (Weinbauer et al.)
6. Effects of ocean acidification on pelagic organisms and ecosystems (Riebesell & Tortell)
7. Effects of ocean acidification on benthic processes, organisms, and ecosystems (Andersson et al.)
8. Effects of ocean acidification on nektonic organisms (Pörtner et al.)
9. Effects of ocean acidification on sediment fauna (Widdicombe et al.)
10. Effects of ocean acidification on marine biodiversity and ec osystem function (Barry et al.)
11. Effects of ocean acidification on the marine source of atmospherically-active trace gases (Hopkins et al.)
12. Biogeochemical consequences of ocean acidification and feedback to the Earth system (Gehlen et al.)
13. The ocean acidification challenges facing science and society (Turley & Kelvin)
14. Impact of climate change mitigation on ocean acidification projections (Joos et al.)
15. Ocean acidification: knowns, unknowns and perspectives (Gattuso et al.)



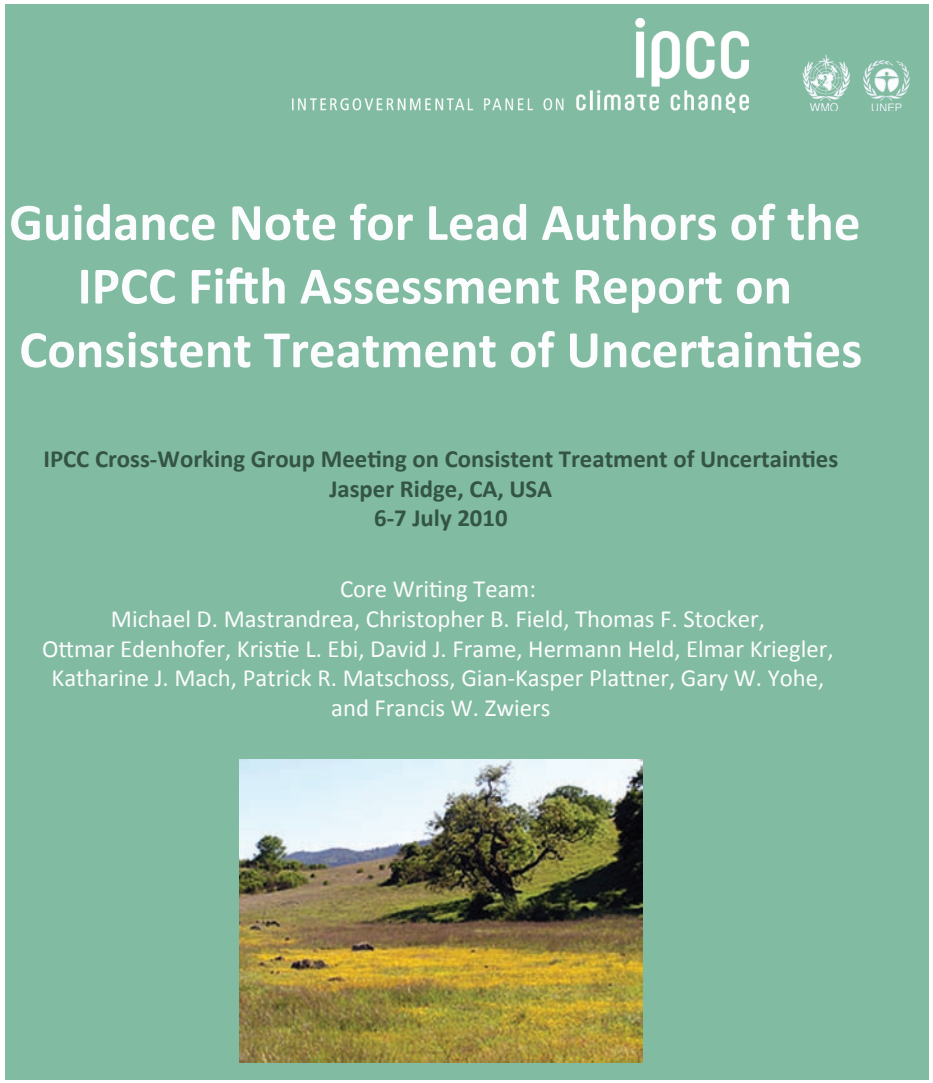
Oxford University Press, September 2011

Assessment



Mastrandrea et al. (2010)

Assessment

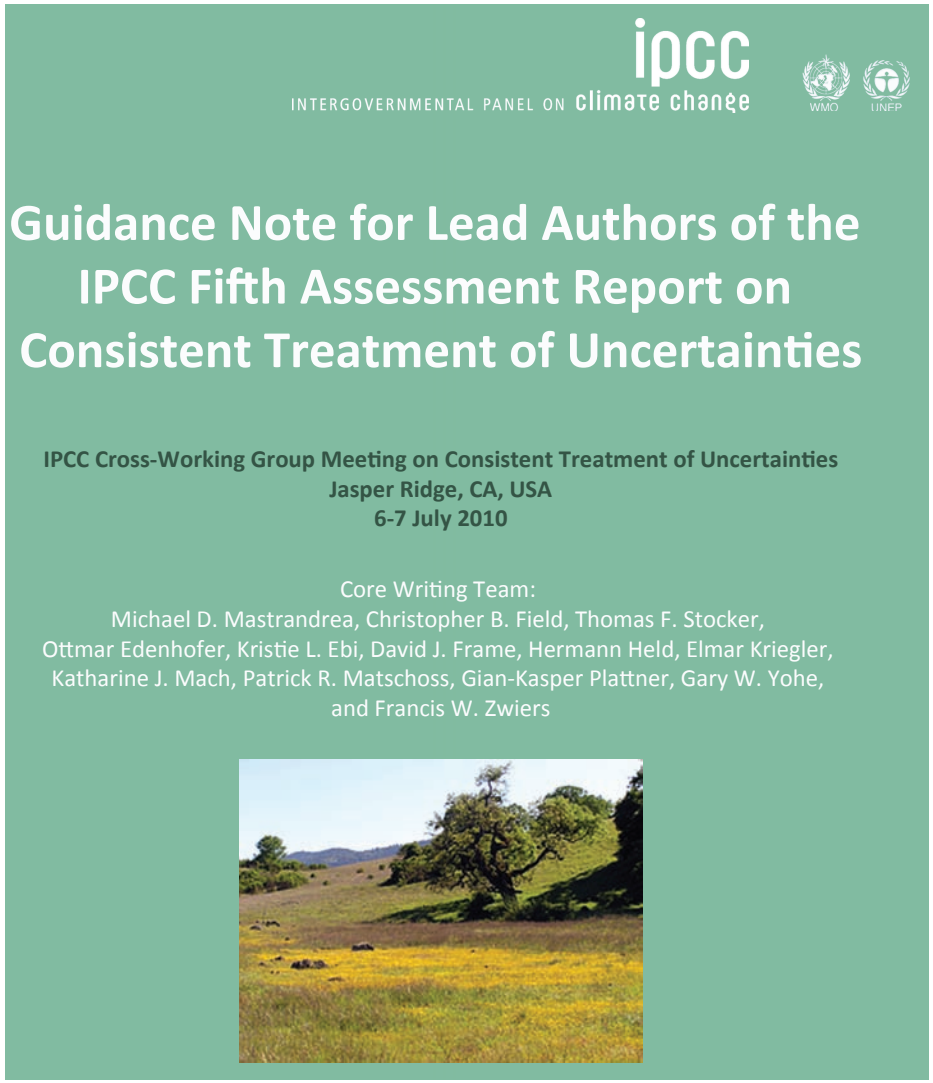


Level of confidence

Level of evidence	Very low	Low	Medium	High	Very high
Limited					
Medium					
Robust					

Mastrandrea et al. (2010)

Assessment



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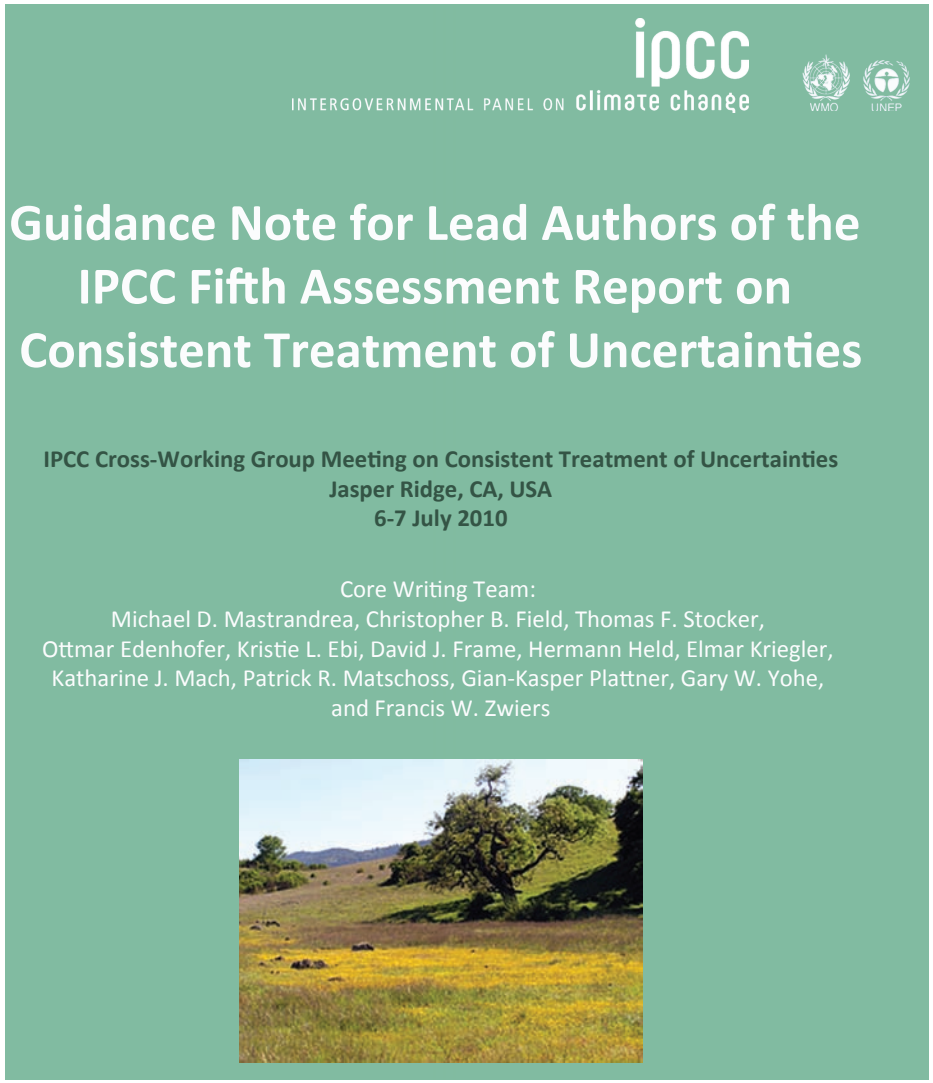
Confidence

Evidence	VL	L	M	H	VH
L					
M					
R					

Mastrandrea et al. (2010)

Assessment



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Level of evidence	Very low	Low	Medium	High	Very high
Limited					
Medium					
Robust					

Confidence

Evidence	VL	L	M	H	VH
L					
M					
R					

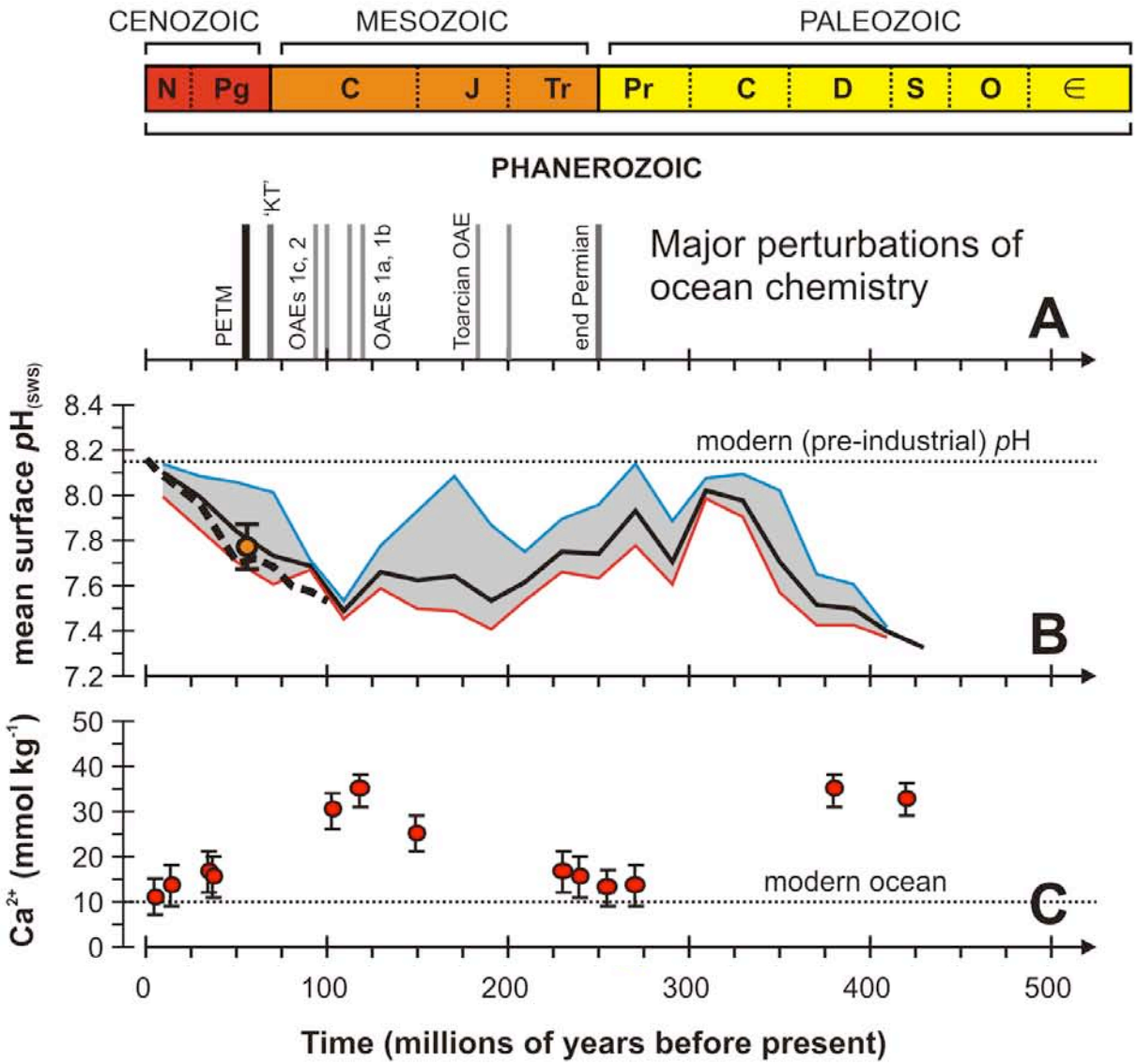
15 declarative statements assessed:

- Chemical aspects
- Biological and biogeochemical responses
- Policy and socio-economic aspects

Mastrandrea et al. (2010)

Chemical aspects

OA occurred in the past



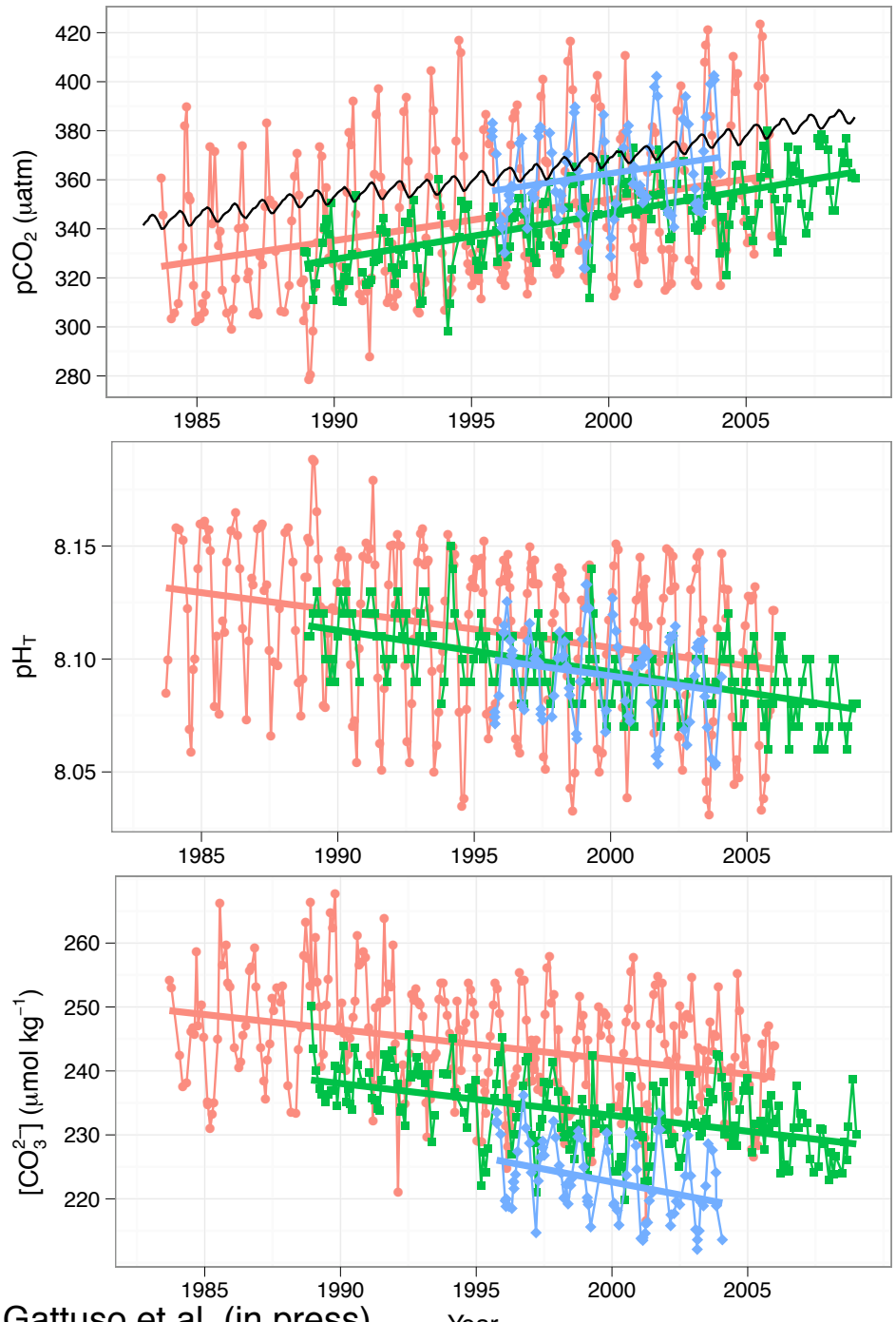
Evidence \ Confidence	VL	L	M	H	VH
L					
M					
R					

Challenge:
Better constrain paleo-reconstructions of the carbonate system

Zeebe & Ridgwell (in press); Gattuso et al. (in press)

OA is in progress

HOT
BATS
ESTOC



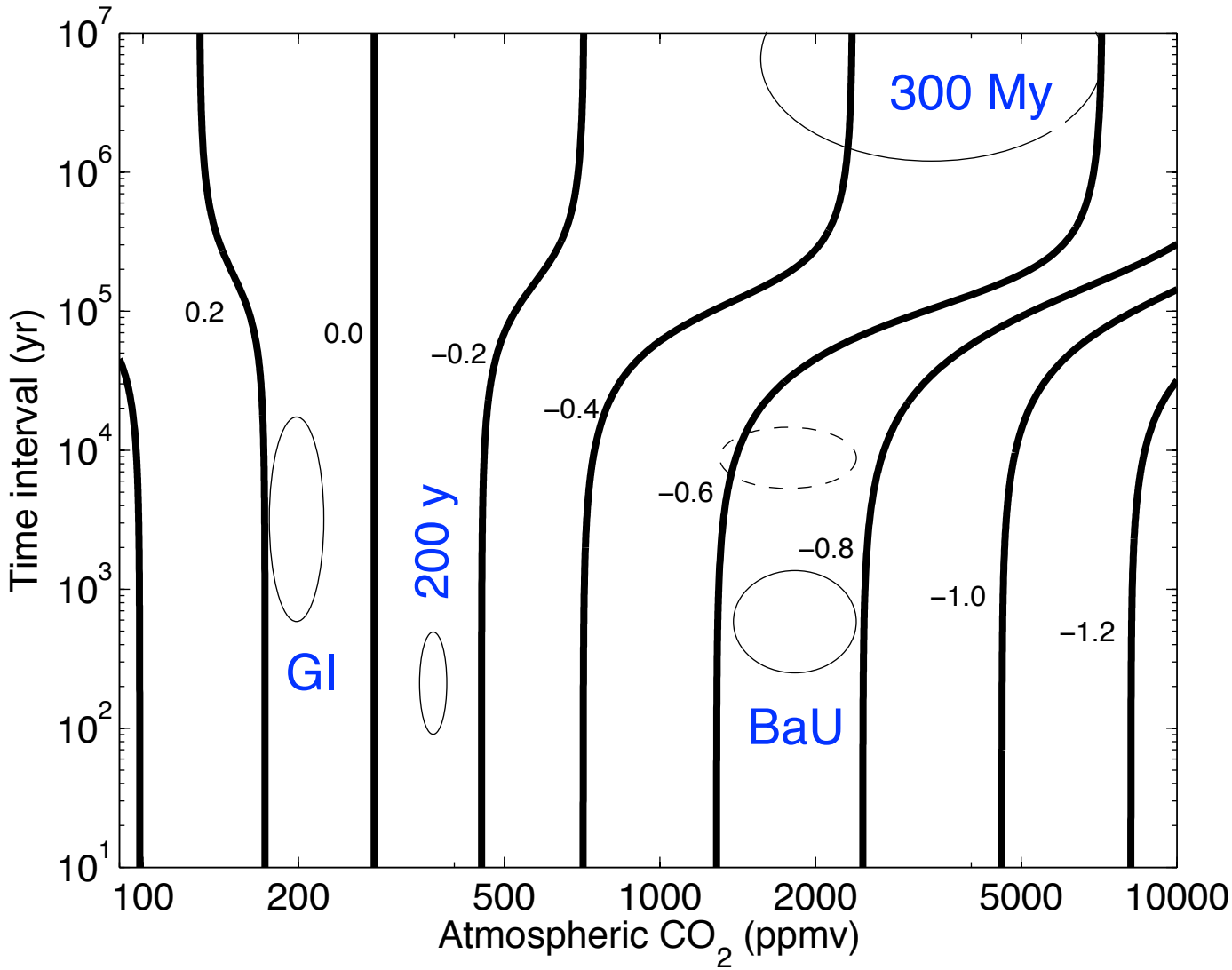
Orr (in press); Gattuso et al. (in press)

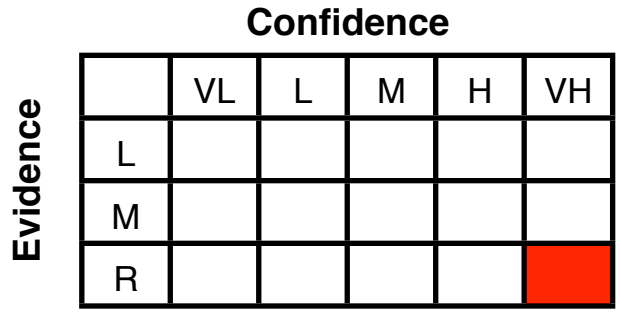
Confidence

Evidence	VL	L	M	H	VH
L					
M					
R					

Challenge:
Better monitoring of key areas (e.g., coastal sites, coral reefs, polar regions and the deep sea)

OA will continue at a rate never encountered in the past 55 Myr

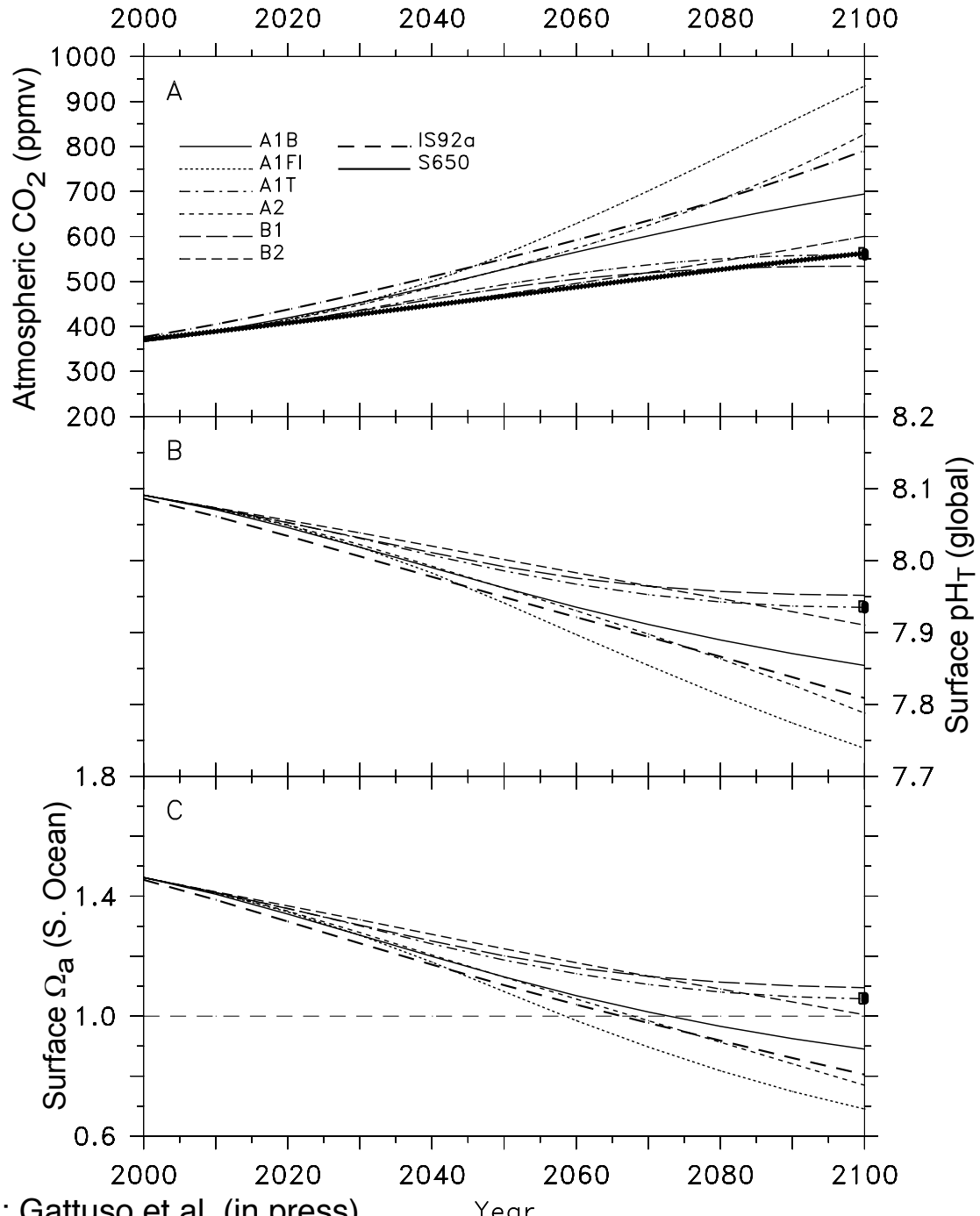




Challenge:
Find two independent carbonate chemistry proxies to reconstruct the ocean carbonate chemistry with a high degree of confidence

Zeebe & Ridgwell (in press); Gattuso et al. (in press)

Future OA depends on emission pathways



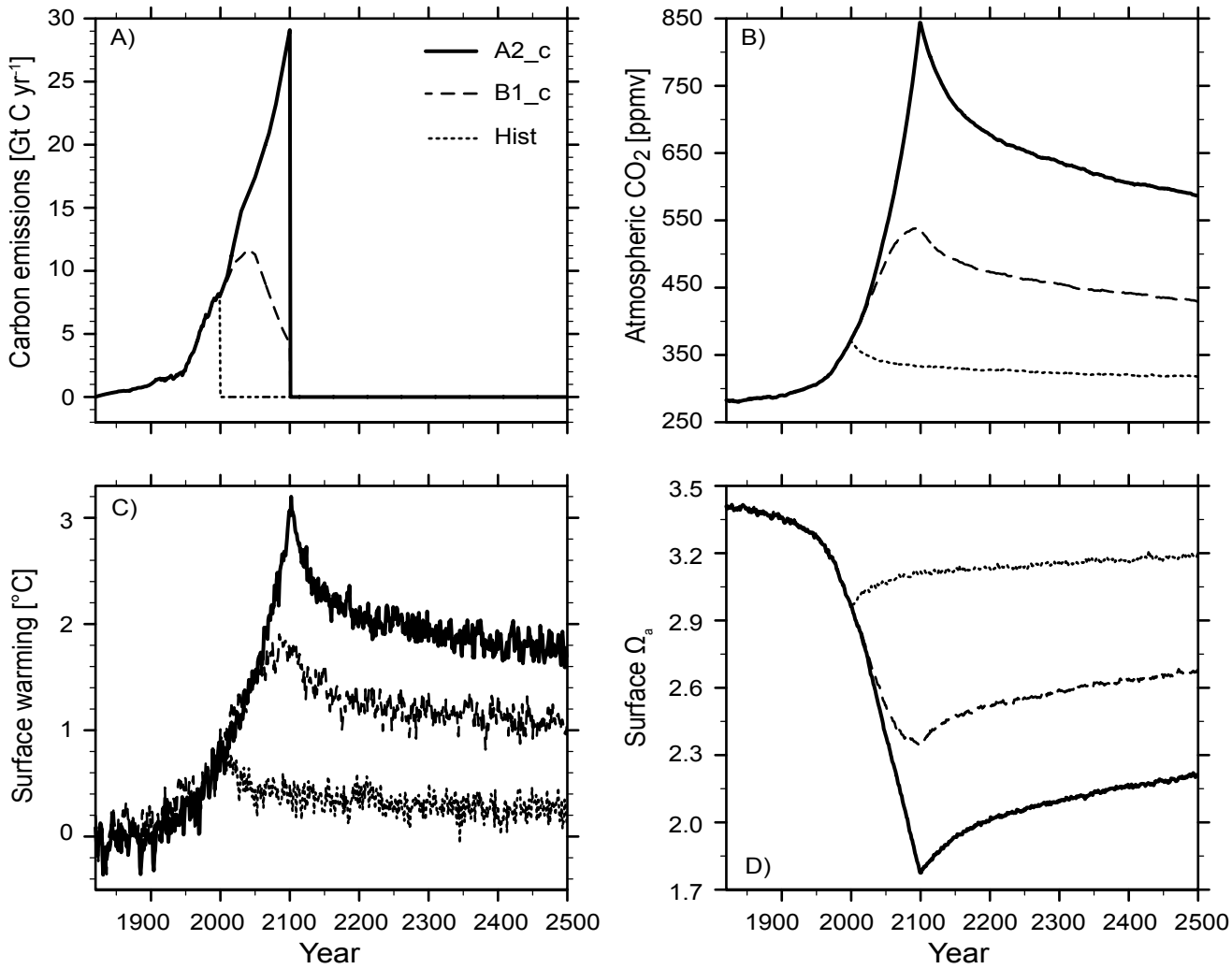
Orr (in press); Gattuso et al. (in press)

Confidence

Evidence	VL	L	M	H	VH
L					
M					
R					

Challenge:
Improve the representation of physical regimes at the regional scale to derive regional estimates

The legacy of historical fossil fuel emissions on OA will be felt for centuries



Confidence

Evidence

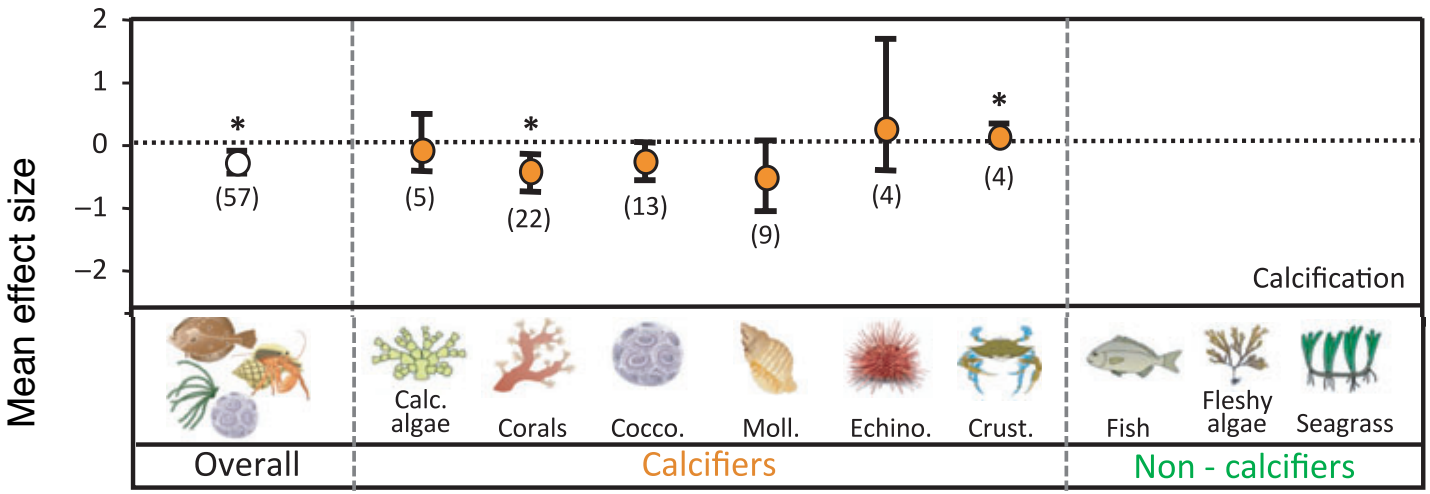
	VL	L	M	H	VH
L					
M					
R					

Challenge:
Improve the representation of physical regimes at the regional scale to derive regional estimates

Joos et al. (in press); Gattuso et al. (in press)

Biological and biogeochemical responses

OA will adversely affect calcification



Confidence

Evidence	VL	L	M	H	VH
L					
M				■	
R					

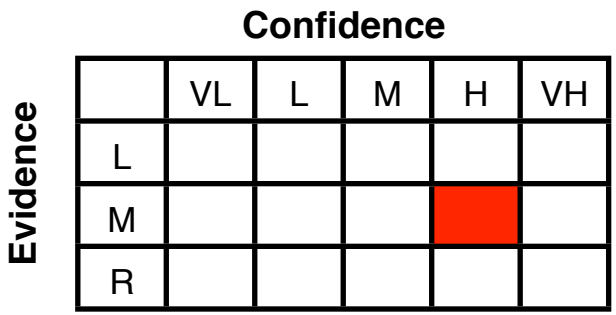
Challenges:

- Determine the mechanisms explaining why a few calcifiers are not affected of stimulated
- Estimate the energetic and physiological trade-offs
- Gain field evidence in addition to that available from CO2 vents
- Identify approaches to improve attribution on field observations

Kroeker et al. (2010); Gattuso et al. (in press)

OA will stimulate photosynthetic carbon fixation

Group	Response	References
Diatoms	↑	Riebesell *et al.* (1993), Burkhardt and Riebesell (1997), Burkhardt *et al.* (1999), Gervais and Riebesell (2001), Wu et al. (2010)
Coccolithophores	↑	Buitenhuis *et al.* (1999), Riebesell *et al.* (2000), Rost *et al.* (2002), Zondervan *et al.* (2002), Leonardos and Geider (2005), Feng et al. (2008), Barcelos e Ramos *et al.* (2010), Shi *et al.* (2009), De Bodt *et al.* (2010), Müller *et al.* (2010), Rickaby *et al.* (2010)
	↓	Sciandra *et al.* (2003)
	↔	Langer *et al.* (2006)
Dinoflagellates	↑	Burkhardt *et al.* (1999), Rost *et al.* (2006)
Cyanobacteria	↑	Barcelos e Ramos *et al.* (2007), Hutchins *et al.* (2007, 2009), Levitan *et al.* (2007), Fu et al. (2008), Kranz *et al.* (2009)
	↔	Czerny *et al.* (2009)
Natural assemblages	↑	Hein and Sand-Jensen (1997), Tortell *et al.* (2002, 2008), Riebesell *et al.* (2007), Bellerby *et al.* (2008), Egge *et al.* (2009)

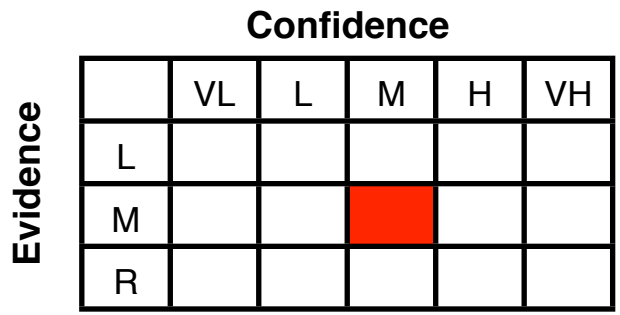


Challenges:

More work needed at the community level and under field conditions to better assess the global magnitude of the response

Riebesell & Tortell (in press); Gattuso et al. (in press)

OA will stimulate nitrogen fixation



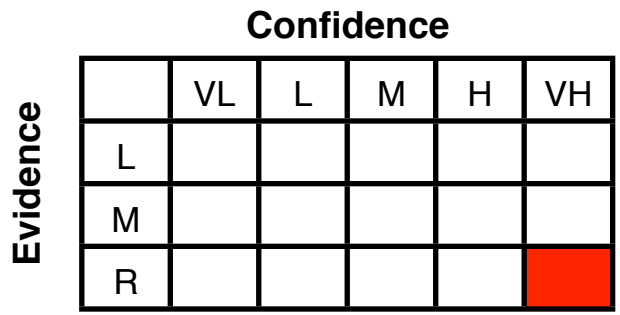
Species	Response	References
Trichodesmium erythraeum	↑	Barcelos e Ramos *et al.* (2007), Hutchins *et al.* (2007), Levitan *et al.* (2007), Kranz *et al.* (2009, 2010)
natural colonies of *Trichodesmium*	↑	preliminary data reported in Hutchins *et al.* (2009)
Crocosphaera watsonii	↑ ↔	Fu *et al.* 2008
Nodularia spumigena	↓	Czerny *et al.* 2009

Challenges:

- Investigate more species to test whether it is a widespread response.
- Determine the interaction with other variables in order to better assess the global magnitude and biogeochemical consequences

Riebesell & Tortell (in press); Gattuso et al. (in press)

Some species or strains are tolerant to OA

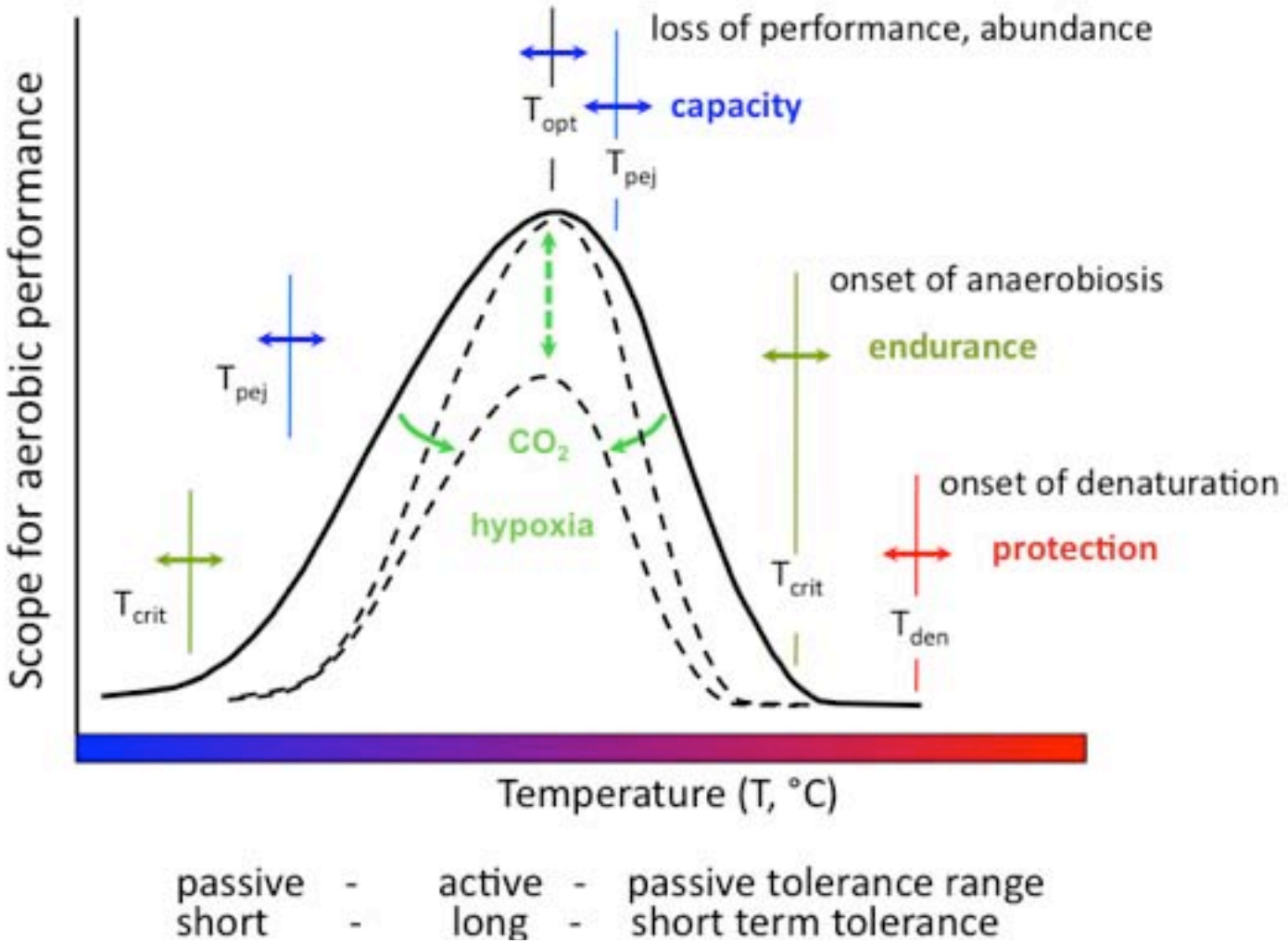


Challenges:

Gain a better understanding of the molecular and biochemical mechanisms underlying processes such as calcification

Pörtner et al. (in press); Gattuso et al. (in press)

Some species or strains are tolerant to OA



Confidence

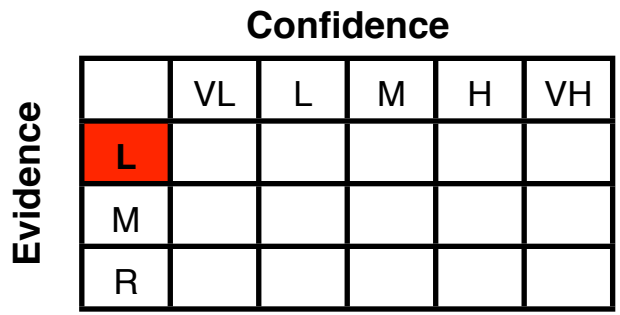
	VL	L	M	H	VH
L					
M					
R					

Challenges:

Gain a better understanding of the molecular and biochemical mechanisms underlying processes such as calcification

Pörtner et al. (in press); Gattuso et al. (in press)

Some taxonomic groups will be able to adapt to OA



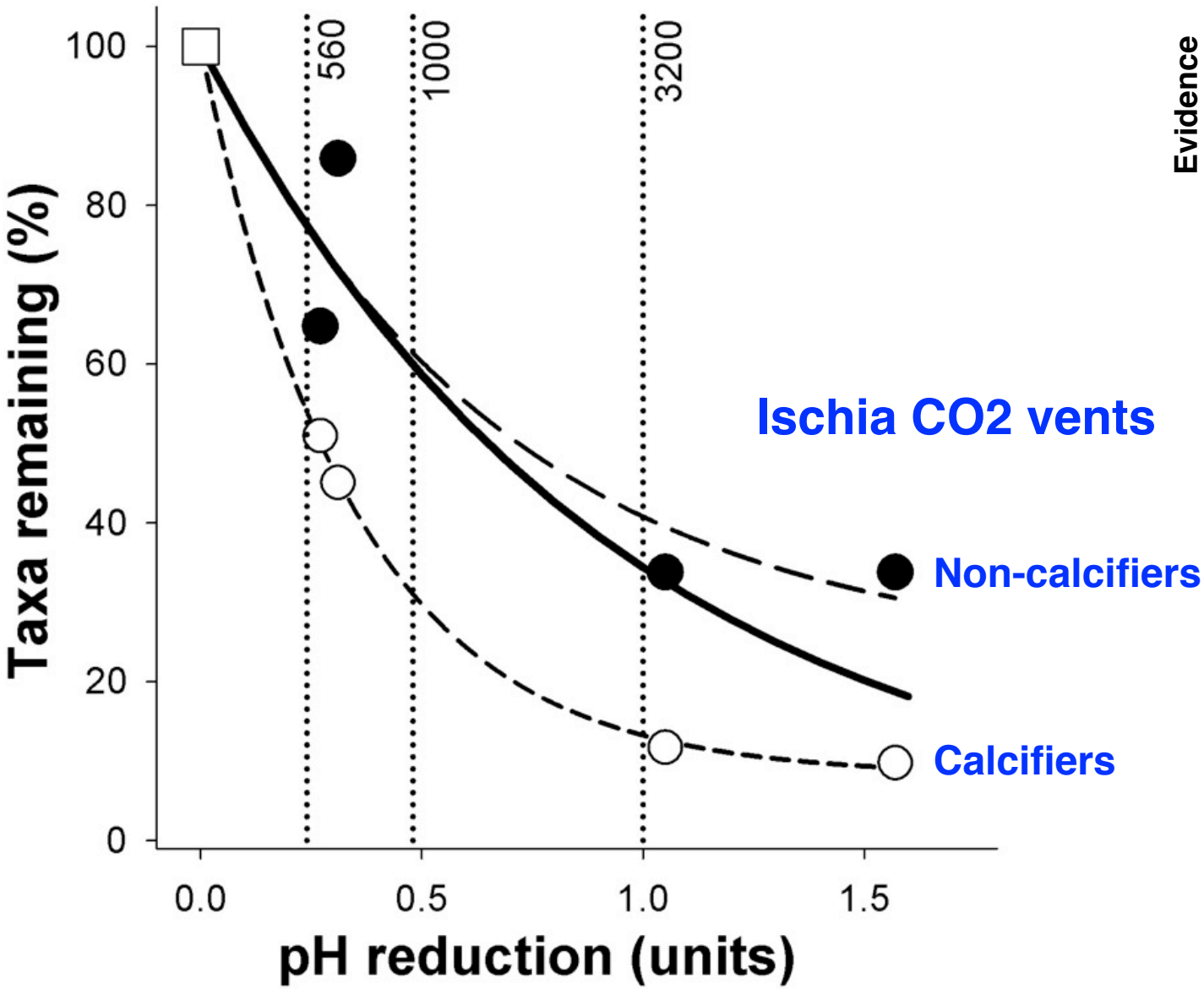
- Two mechanisms to consider:
  - phenotypic plasticity
  - genetic (evolutionary) changes
- Geologic record: increased rate of extinction when environmental changes were fast

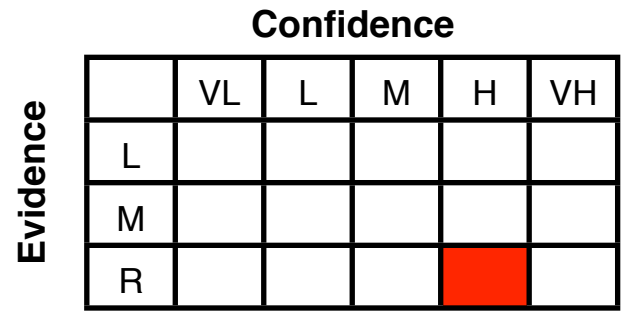
Challenges:

- Initiate long-term experiments
- Identify approaches and tools to estimate the adaptation potential

Riebesell & Tortell (in press); Gattuso et al. (in press)

OA will change the composition of communities



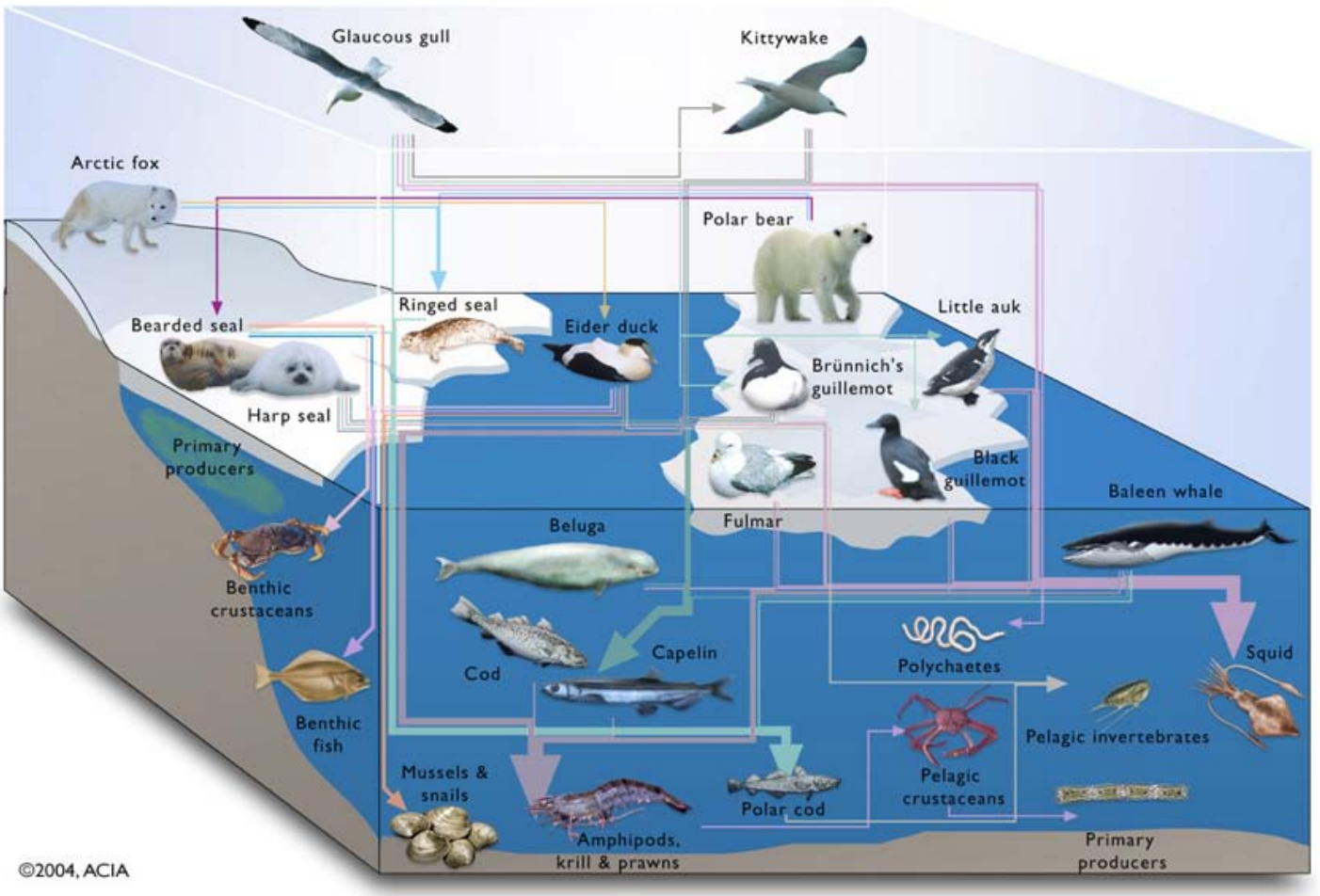


Challenges:

- Collect better information on non-calcifiers in the paleorecord
- Determine the magnitude of the change in present key ecosystems

Barry et al. (in press); Gattuso et al. (in press)

OA will impact food webs and higher trophic levels



Confidence

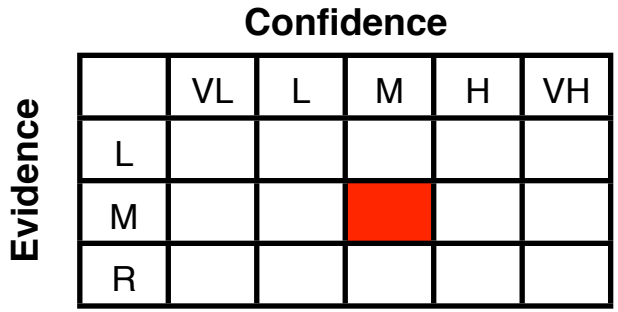
Evidence	VL	L	M	H	VH
L					
M					
R					

Challenges:

- Determine how species that may disappear will be replaced
- Will replacement species have a similar nutritional value?

Cooley & Doney (2009); Gattuso et al. (in press)

OA will have biogeochemical consequences at the global scale



Process	Sign of feedback	Sensitivity	Capacity	Longevity
Calcification	negative	+ [1]	+	+ [1]
Ballast effect	positive		+++	+++
Extracellular organic matter prod.	negative	++ [1]	+++	[2]
Stoichiometry	negative	++ [1]	++	++
Nitrogen fixation	negative	++ [1]	+	[2]

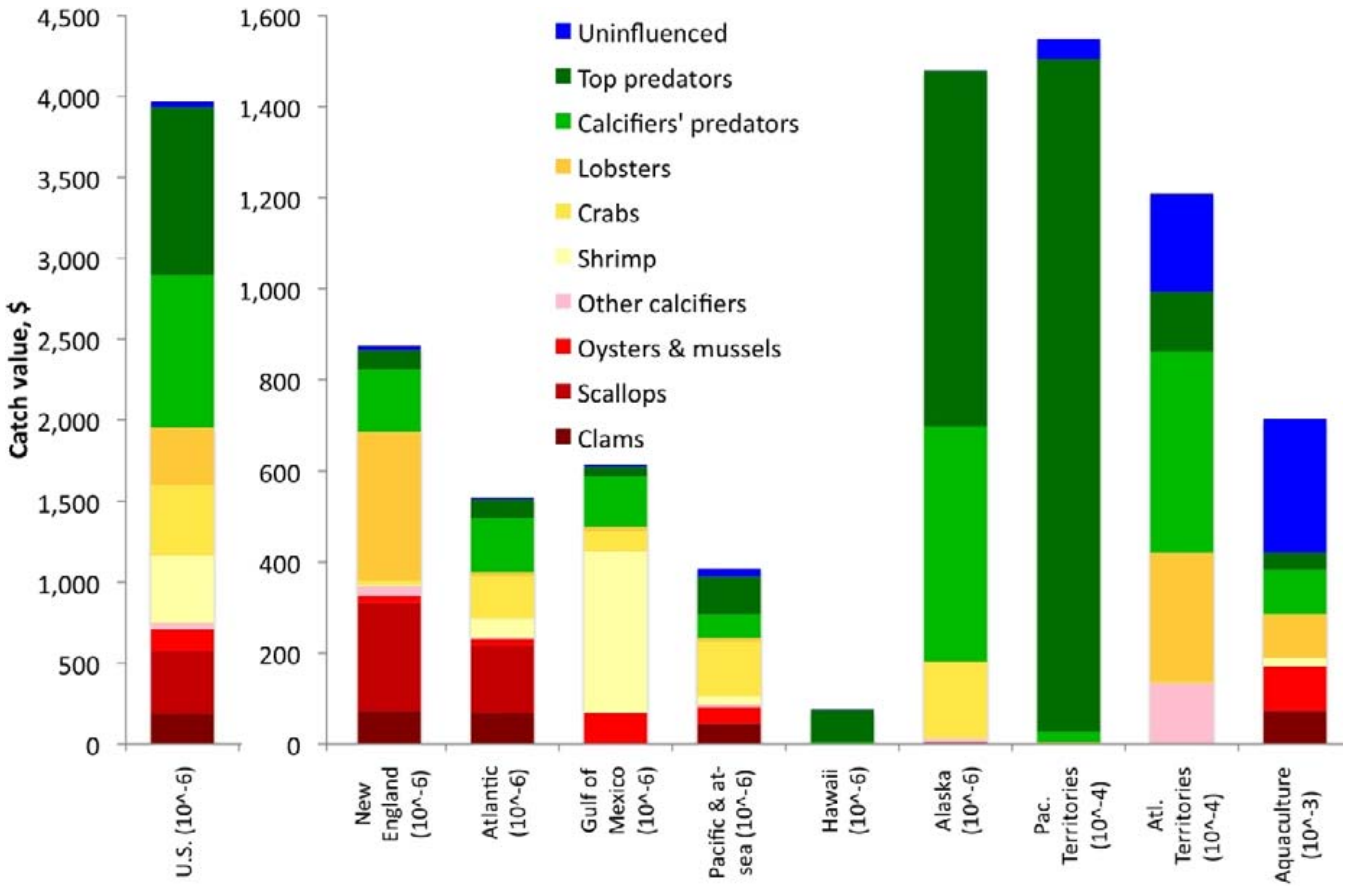
Challenges:

Better understanding of key processes as a function of carbonate system variables needed to improve model parametrization

Riebesell & Tortell (in press); Gehlen et al. (in press); Gattuso et al. (in press)

Policy and socio-economic aspects

There will be socio-economic consequences



Confidence

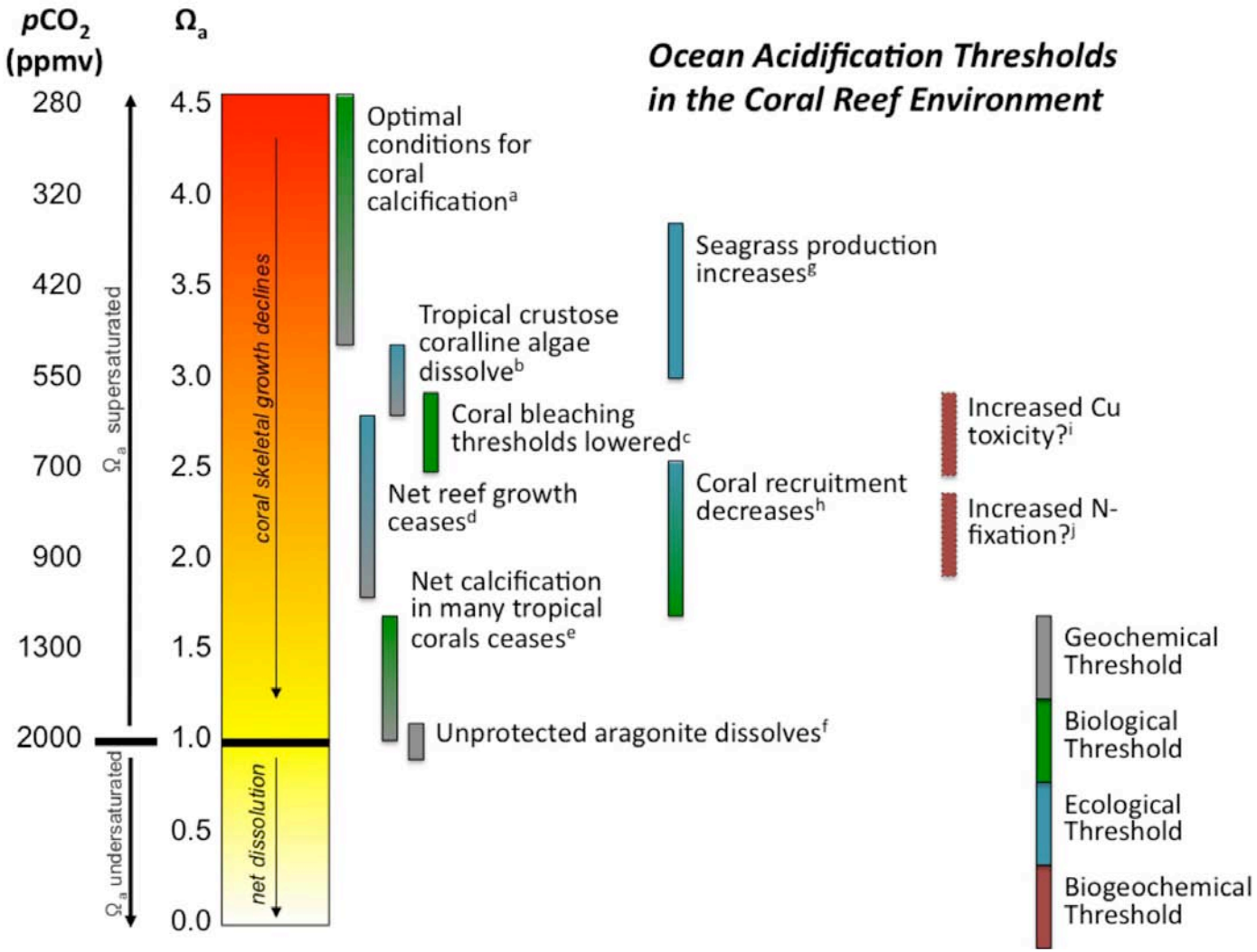
Evidence	VL	L	M	H	VH
L					
M					
R					

Challenges:

- Quantify the monetary value of the goods and services that oceans provide
- Assess how these may be impacted by ocean acidification.

Cooley & Doney (2009); Turley & Boot (in press); Gattuso et al. (in press)

An OA threshold that must not be exceeded can be defined



Evidence \ Confidence	VL	L	M	H	VH
L					
M					
R					

Challenges:

- Initiate and sustain an international effort to compile the increasing number of data being published in order to defined threshold(s)
- Investigate the need to consider thresholds based on geographic location, species and ecosystems to advise decision-makers

Kleypas & Gattuso (in prep.); Gattuso et al. (in press)

Summary on statements

- **Chemical effects**: robust evidence and high certainty
- **Biological and ecological effects**: much less certain
  - calcification, primary production, nitrogen fixation and biodiversity will be altered but with an unknown magnitude
  - some cannot be assessed
- **Biogeochemistry, society and the economy** may change; whether it will be significant or not is also unknown

Systems at risk

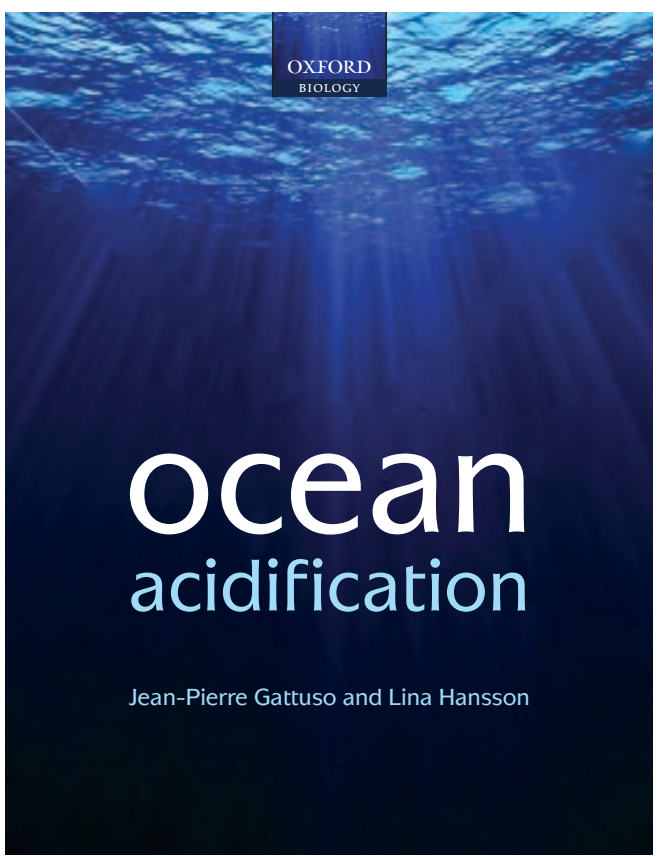
- Polar areas
- Deep-sea environments
- Coral reefs
- Nearshore ecosystems

Past limitations and future prospects

- Limited workforce and funding
- Inappropriate or inconsistent methods
- Duration of experiments
- Interactions with other stressors
- Lack of field evidence other than around CO_2 vents
- Limited work at the community level
- Difficulties to perform meta-analysis
- Model development
- Need for a coordinated international effort

More information

- **Project web site**: epoca-project.eu
- **Ocean acidification blog**
- **Blog EPOCA Arctic campaigns**
- **Movie** “Tipping Point”
- **Book**: Oxford University Press, Sep. 2011



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  - Marion Gehlen
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