Arctic Ocean acidification: present understanding, management requirements and future research strategies

Richard Bellerby

SKLEC-NIVA Centre for Marine and Coastal Research
East China Normal University, Shanghai, China

Norwegian Institute for Water Research, Bergen, Norway

Jeremy Mathis, Wenting Chen, Kumiko Azetsu-Scott, Lisa Miller, Sam Dupont, Howard Browman

Norwegian Institute for Water Research

SKLEC
河口海岸学国家重点实验室
State key Laboratory of Estuarine and Coastal Research

Key Findings: Ocean Chemistry

Key finding 1
Arctic marine waters are experiencing widespread and rapid ocean acidification

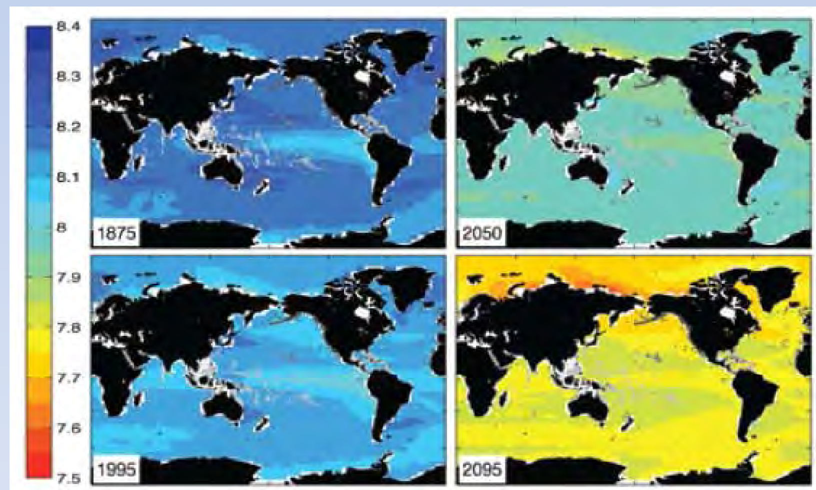
Key finding 2
The primary driver of ocean acidification is uptake of carbon dioxide emitted to the atmosphere by human activities

Key finding 3
The Arctic Ocean is especially vulnerable to ocean acidification

Key finding 4
Acidification is not uniform across the Arctic Ocean

pH	H+ (moles per liter)	change in acidity
7.2	6.3×10^{-8}	+900%
7.3	5.0×10^{-8}	+694%
7.4	4.0×10^{-8}	+531%
7.5	3.2×10^{-8}	+401%
7.6	2.5×10^{-8}	+298%
7.7	2.0×10^{-8}	+216%
7.8	1.6×10^{-8}	+151%
7.9	1.3×10^{-8}	+100%
8.0	1.0×10^{-8}	+58%
8.1	7.9×10^{-9}	+26%
8.2	6.3×10^{-9}	

Average global surface ocean pH has fallen from a pre-industrial value of 8.21 to 8.10, corresponding to an increase in acidity of 28.8%. Values of 7.8–7.9 are expected by 2100, representing a 100–150% increase in acidity (NOAA/PMEL)



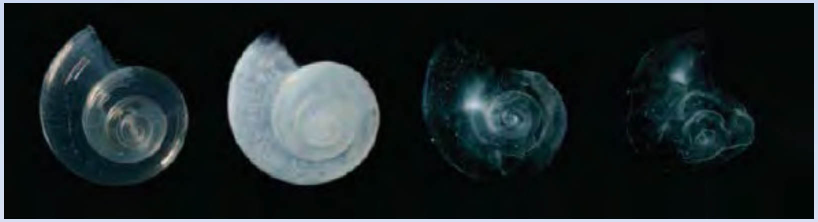
Ocean surface pH - historical values and projected future values based on emission projections

Key Findings: Biological responses

Key finding 5
Arctic marine ecosystems are highly likely to undergo significant change due to ocean acidification

Key finding 6
Ocean acidification will have direct and indirect effects on Arctic marine life. It is likely that some marine organisms will respond positively to new conditions associated with ocean acidification, while others will be disadvantaged, possibly to the point of local extinction

Key finding 7
Ocean acidification impacts must be assessed in the context of other changes happening in Arctic waters



Preventing pteropods from forming and maintaining their protective shells is one of better know examples of effects of ocean acidification on marine organisms. Pteropods are key species in Arctic marine food webs

Key Findings: Socio-economic implications

Key finding 8
Ocean acidification is one of several factors that may contribute to alteration of fish species composition in the Arctic Ocean

Key finding 9
Ocean acidification may affect Arctic fisheries

Key finding 10
Ecosystem changes associated with ocean acidification may affect the livelihoods of Arctic peoples

Arctic commercial fisheries catch in excess of 7 million tonnes of fish, crabs and shrimp each year, worth billions of US$ and forming a significant contribution to many northern economies.

Policy-relevant recommendations

It is recommended that the Arctic Council

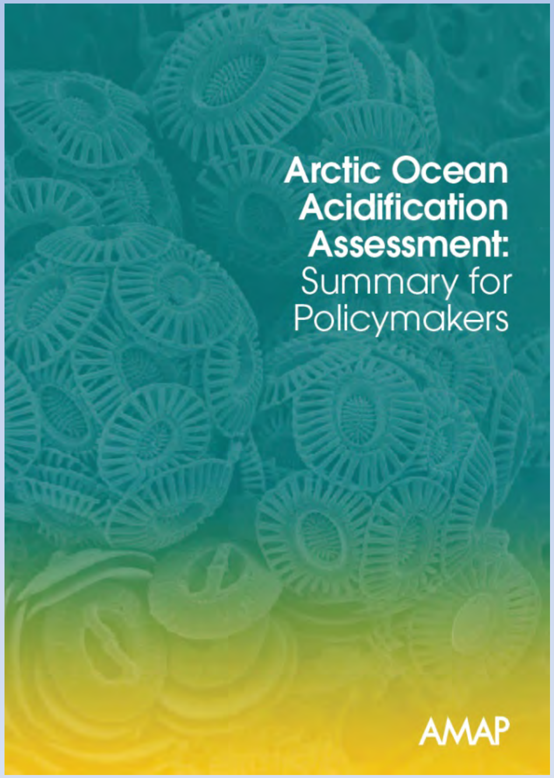
2. Call for enhanced research and monitoring efforts that expand understanding of acidification processes and their effects on Arctic marine ecosystems and northern societies that depend on them.

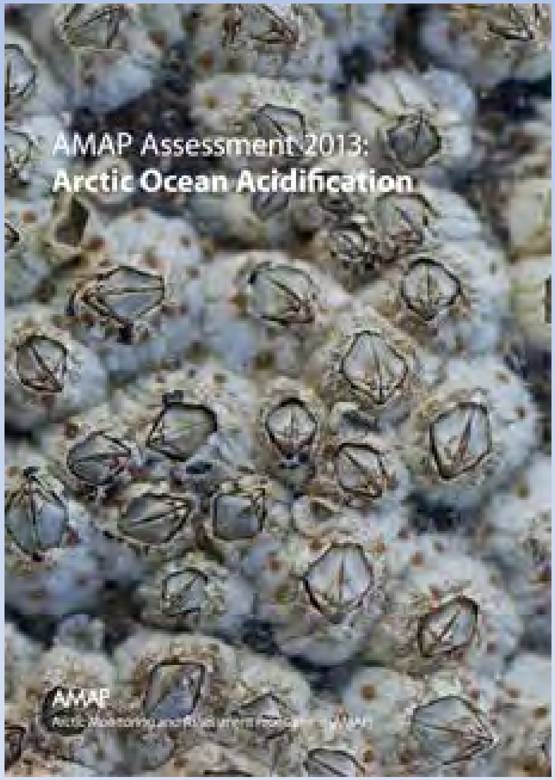
The biological, social, and economic effects of ocean acidification are potentially significant for the Arctic nations and their peoples, as well as global society.

There remain large gaps in knowledge that currently prevent reliable projections of these impacts.

Arctic marine resources provide the foundation for the diet, culture and well-being of many Arctic indigenous people

Lots of interesting reading on Arctic Ocean acidification





AMAP Arctic Ocean Acidification Assessment

Summary for Policy-makers:

http://amap.no/documents/

Films:

https://vimeo.com/groups/189916

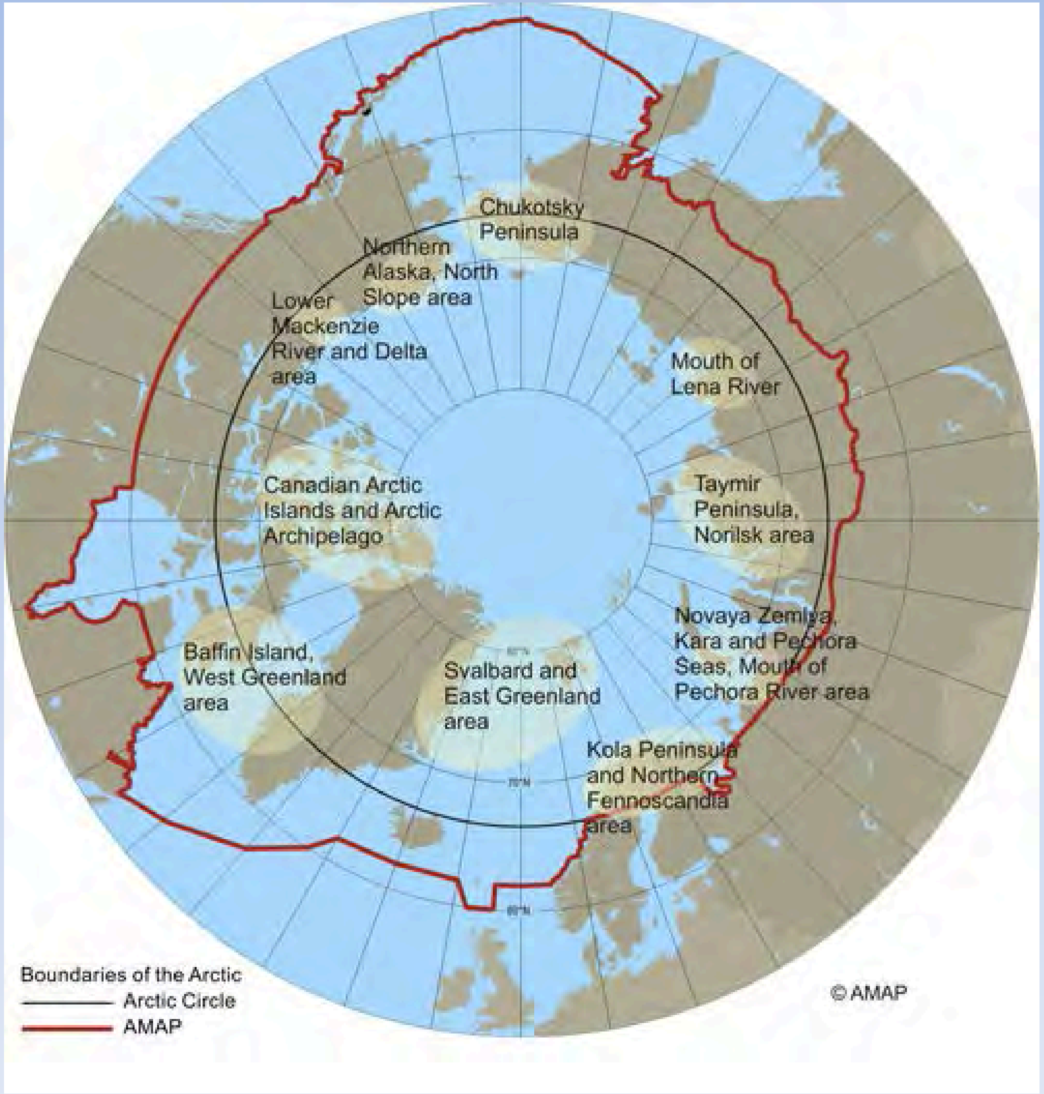
The core foci of AMAP OA 2017

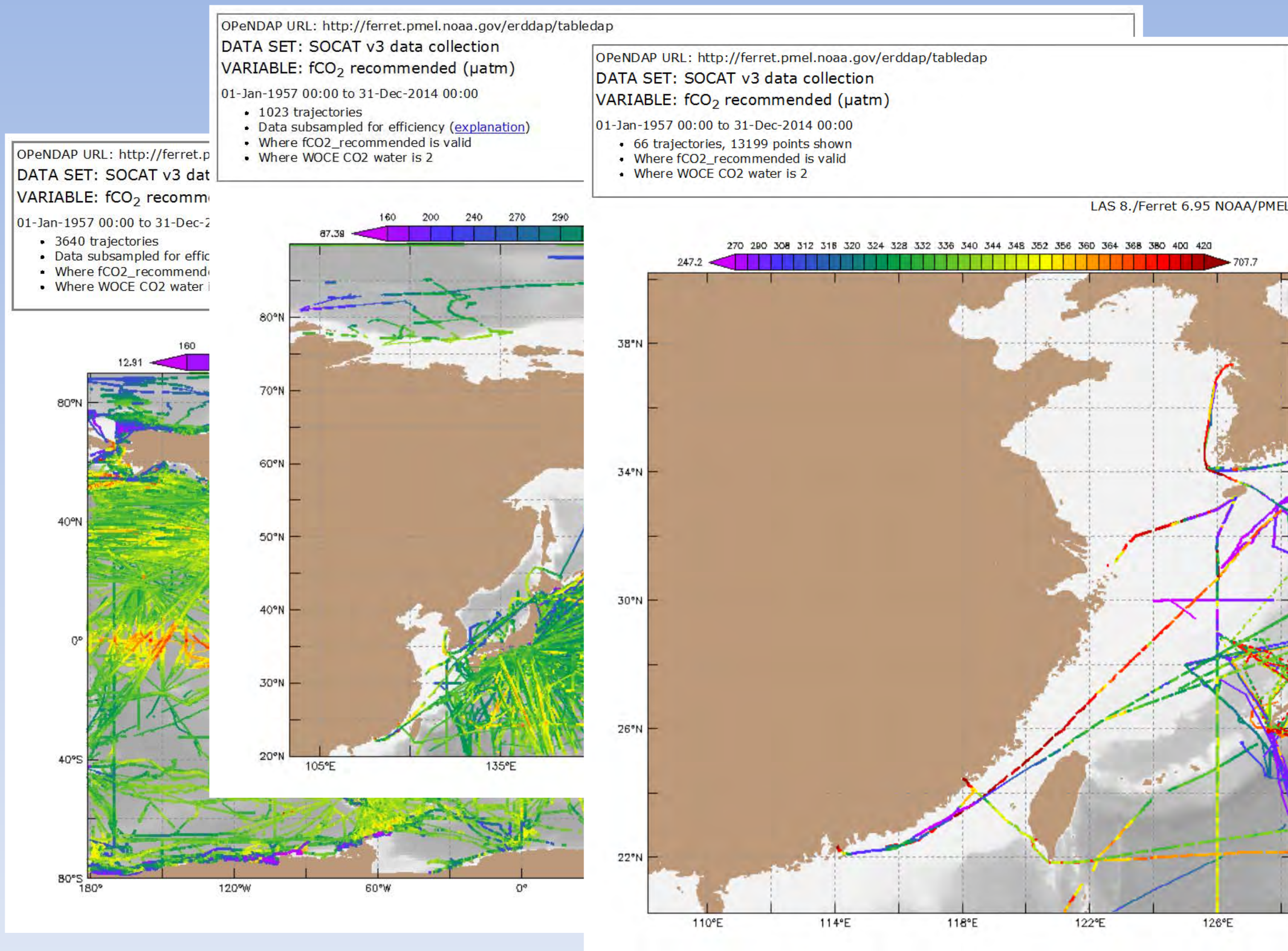
- Tele-connections – how Arctic impacts global systems
- The ecological framework of OA response
- Socioeconomic and cultural consequences
- Guidance for management of change

What Science is needed

- Focused observations of coupled climate-carbon-biological systems
- An evaluation of downstream services and challenges that OA provide to the global ocean
- The identification of economically and culturally important ecosystems and the services they provide
- Relevant experiments on dominant and keystone species
- An integrated evaluation of the “whole” consequences (the challenges and the opportunities) of ocean acidification

The AMAP "Arctic"





OPeNDAP URL: http://ferret.pmel.noaa.gov/erddap/tabledap
DATA SET: SOCAT v3 data collection
VARIABLE: fCO2 recommended (μatm)
01-Jan-1957 00:00 to 31-Dec-2014 00:00
3640 trajectories
80°N
40°N
0°
40°S
80°S
180°
120°W
60°W
0°
OPeNDAP URL: http://ferret.pmel.noaa.gov/erddap/tabledap
DATA SET: SOCAT v3 data collection
VARIABLE: fCO2 recommended (μatm)
01-Jan-1957 00:00 to 31-Dec-2014 00:00
1023 trajectories
Data subsampled for efficiency (explanation)
Where fCO2_recommended is valid
Where WOCE CO2 water is 2
80°N
70°N
60°N
50°N
40°N
30°N
20°N
105°E
135°E
OPeNDAP URL: http://ferret.pmel.noaa.gov/erddap/tabledap
DATA SET: SOCAT v3 data collection
VARIABLE: fCO2 recommended (μatm)
01-Jan-1957 00:00 to 31-Dec-2014 00:00
66 trajectories, 13199 points shown
Where fCO2_recommended is valid
Where WOCE CO2 water is 2
LAS 8./Ferret 6.95 NOAA/PMEL
247.2
707.7
38°N
34°N
30°N
26°N
22°N
110°E
114°E
118°E
122°E
126°E

The North Pacific has to be shown to be decreasing in pH

Total pH reduction

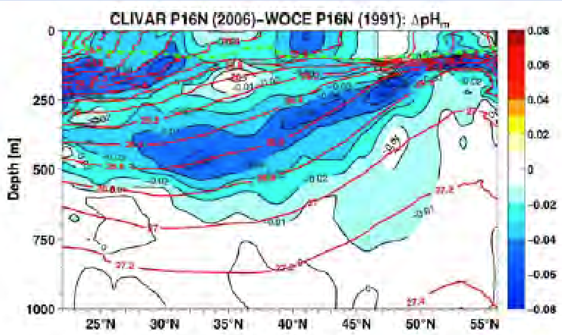


Figure 2. ΔpH_m, the change in seawater pH between 1991 and 2006: $pH_{2006} - pH_{1991}$. Red contours show isopycnal surfaces. The dashed green line marks the estimated 152°W late-winter mixed layer depth (Levitus 1998 climatology [*Antonov et al.*, 1998; *Boyer et al.*, 1998]) and is roughly equivalent to the average mixed layer depth between the two March cruises.

Some of the pH reduction attributed to circulation changes

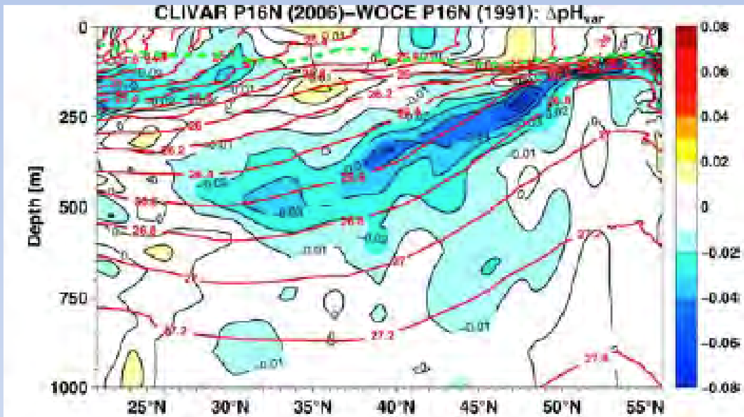


Figure 3. ΔpH_{var}: pH change attributed to natural interdecadal/interannual DIC variability between 1991 and 2006. Details follow Figure 2.

GEOPHYSICAL RESEARCH LETTERS, VOL. 37, L02601, doi:10.1029/2009GL040999, 2010

Click Here for Full Article

Direct observations of basin-wide acidification of the North Pacific Ocean

Robert H. Byrne,[1] Sabine Mecking,[2] Richard A. Feely,[3] and Xuewu Liu[1]

Report card provided to EU Marine Strategy Framework Directive to describe Good Environmental Status

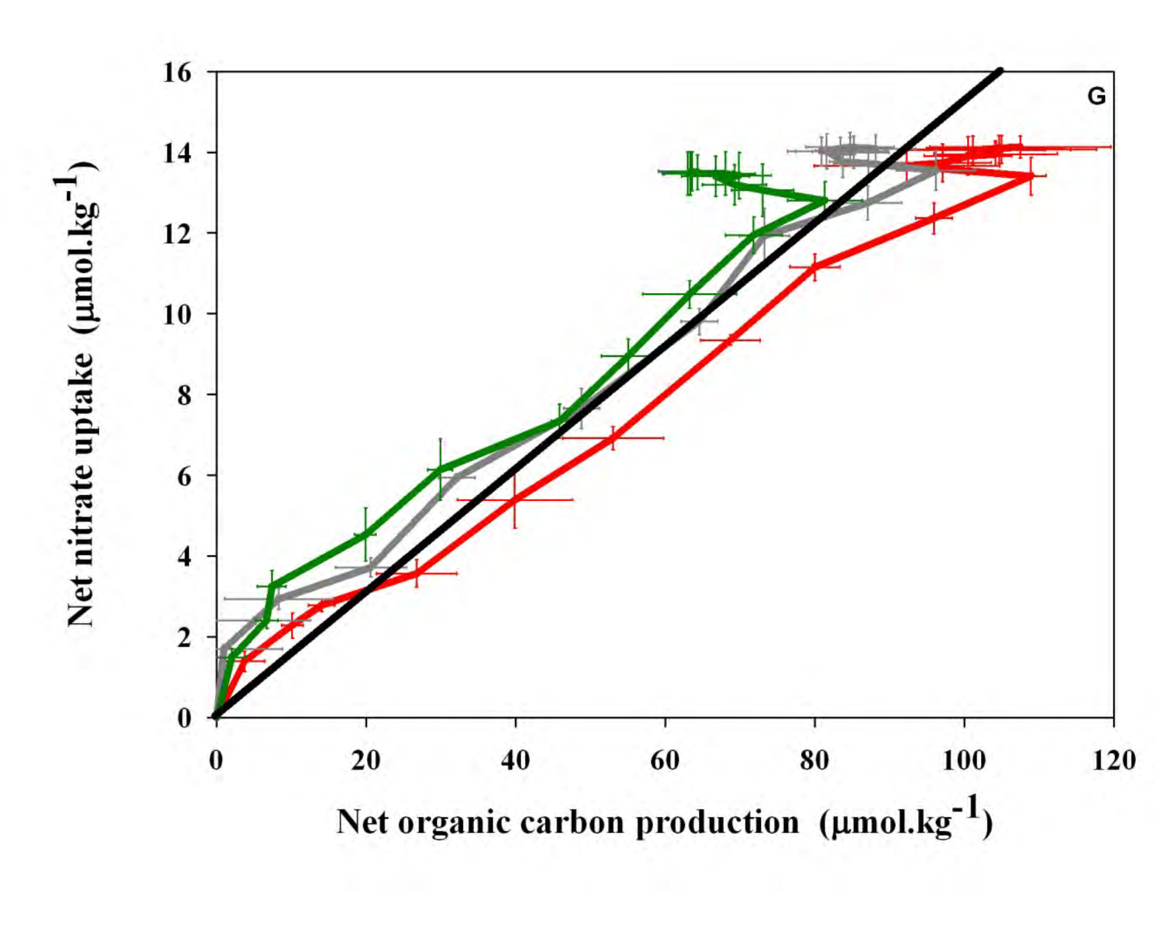
Combined resistance and resilience for ecological components

- Resistance defines whether or not a particular pressure can drive a component beyond its acceptable threshold level.
- Resilience is the time taken to recovery given a cessation of the pressure

		Resistance	
		Low	High
Resilience	None	3	3
	Low	3	2
	Medium	2	1
	High	1	1

Meece.eu

Enhanced biological carbon consumption in a high CO_2 ocean?

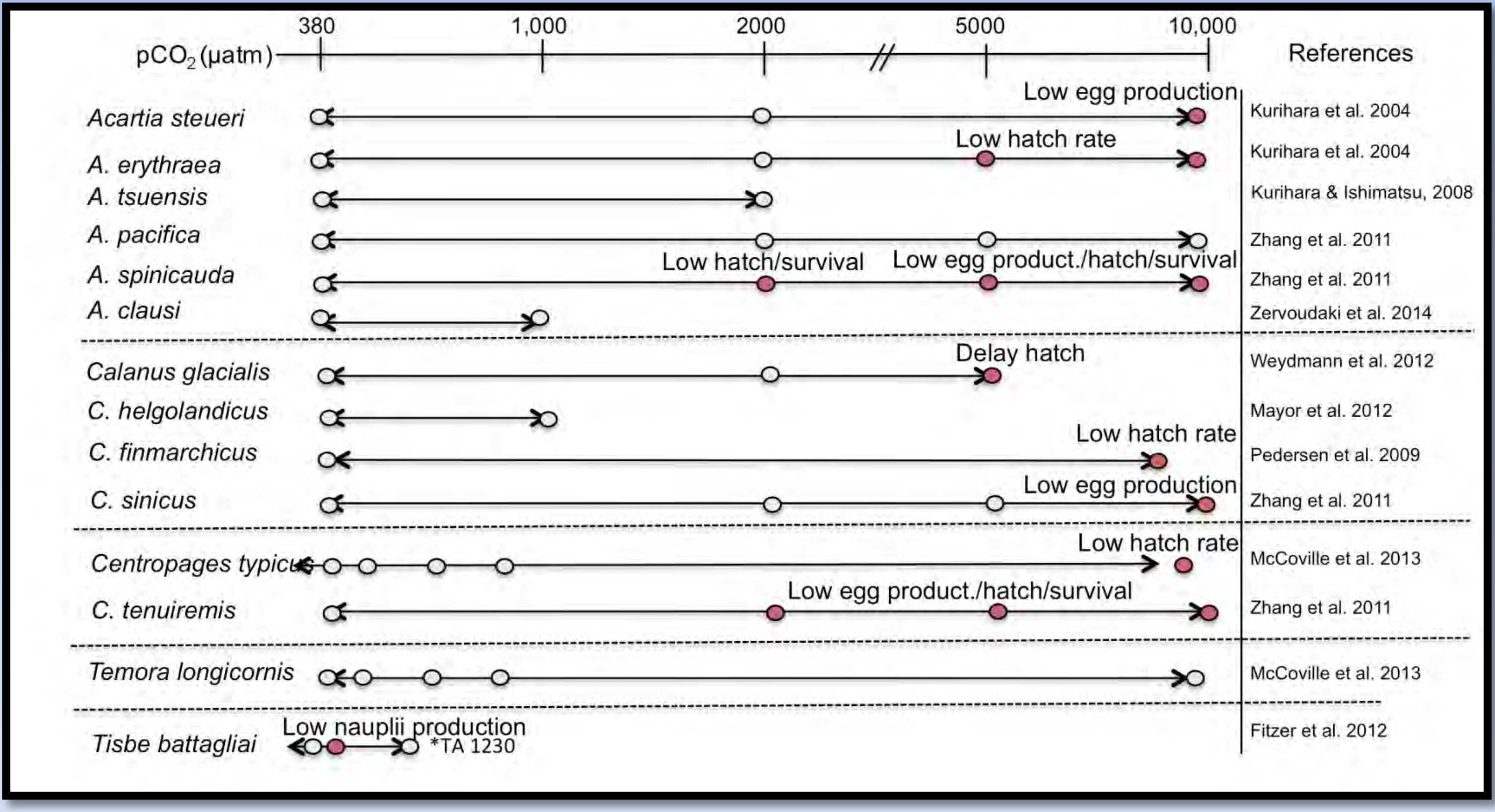


Atmospheric CO_2 scenario

Present
2100
2200

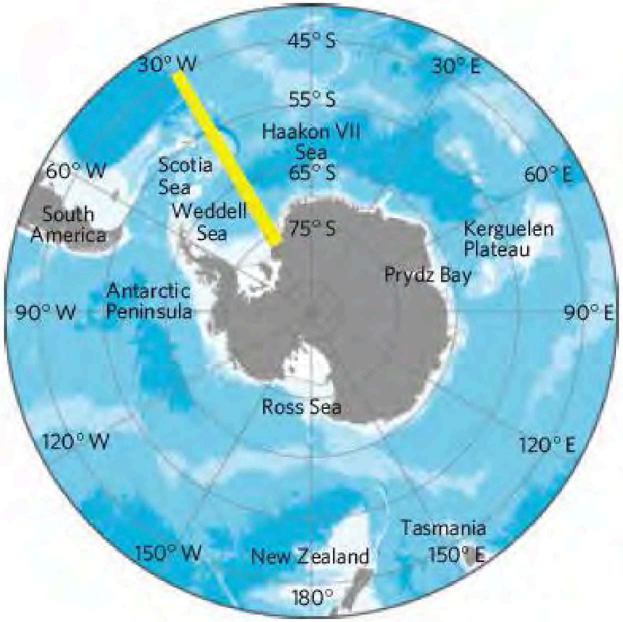
Bellerby et al., 2008

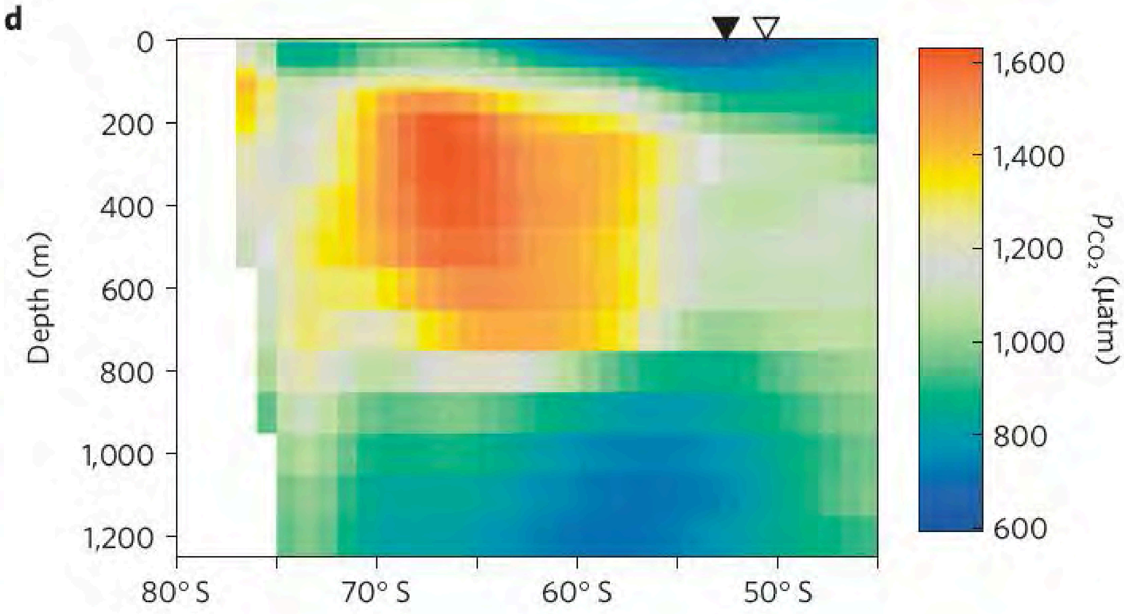
Variable responses of copepods to high (and very high!) CO_2.



Red symbols indicate CO_2 concentrations that were demonstrated to have negative impacts on the respective copepod species

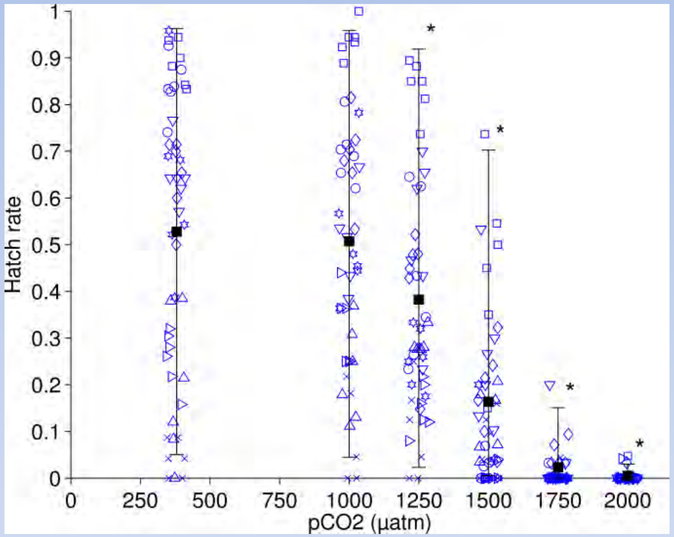
A krill story: high depth dependent ocean acidification simulated for the future



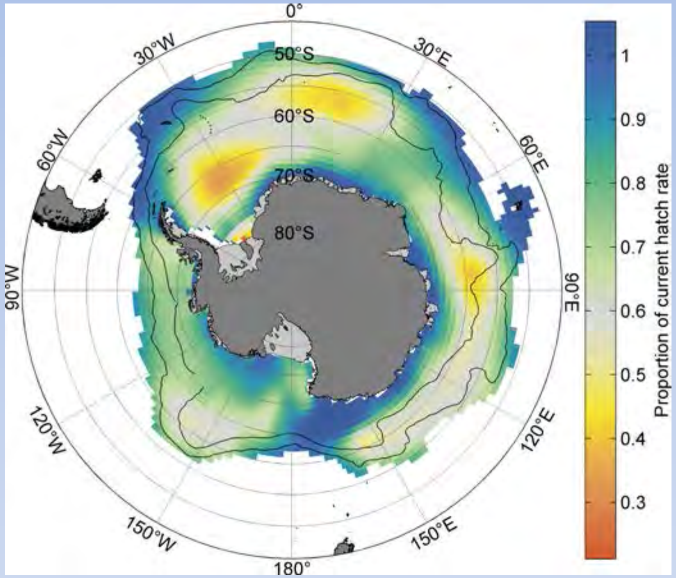


Kawaguchi et al., 2013

Simulated ocean acidification would challenge krill hatching success



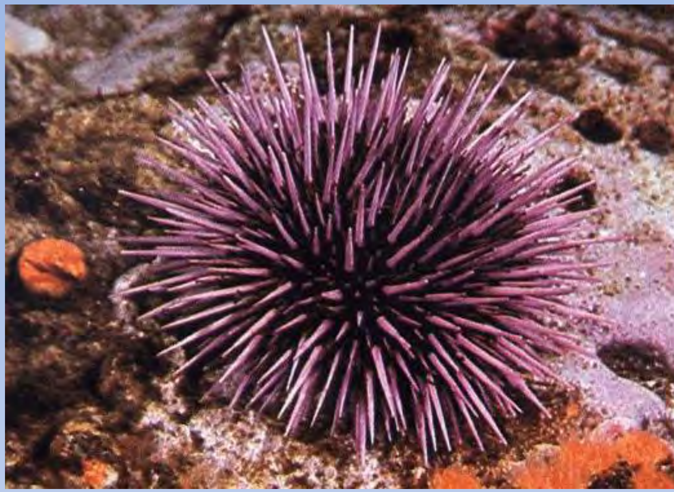
Observed (open symbols) and modeled mean (black squares) krill egg hatch rates at six experimental pCO_2 levels.



Circumpolar risk map of krill hatching success under projected future pCO_2 level following the RCP 8.5 emission scenario.

Kawaguchi et al., 2013

Sea urchin reproductio



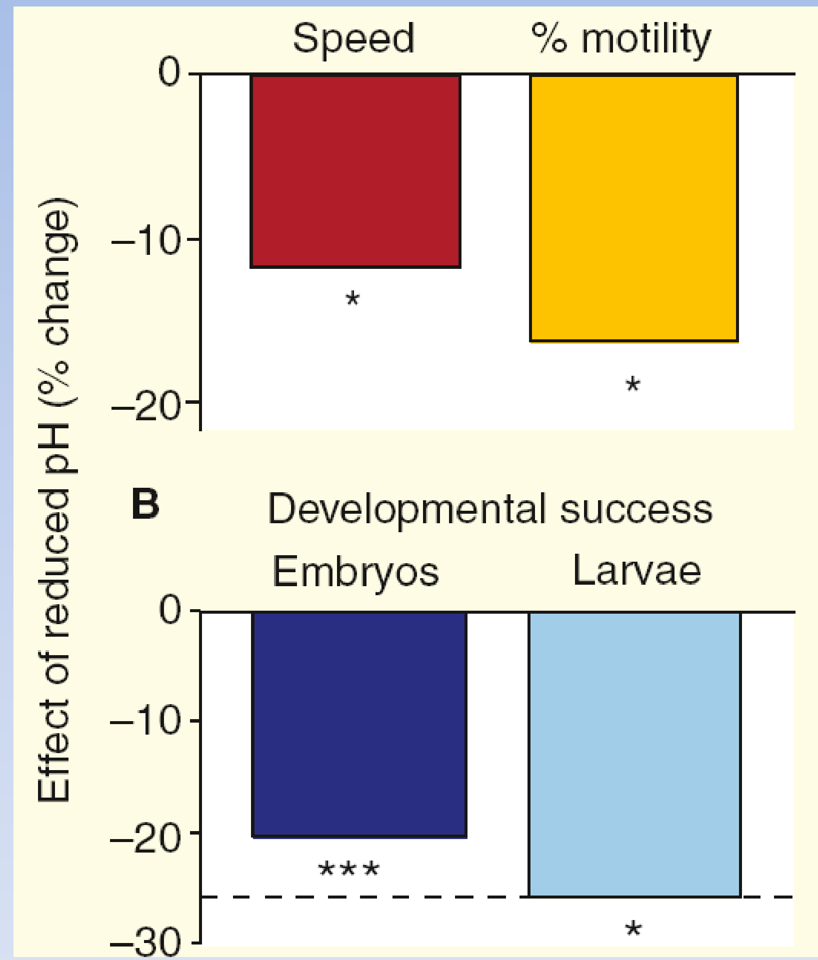
Reduction in:

sperm swimming speed

sperm motility

embryo development

larval development



Havenhand et al., *Current Biology*, 2009

Estimated 2050 distribution of N=1066 species using projected temperature map

$N_{invasion}$=

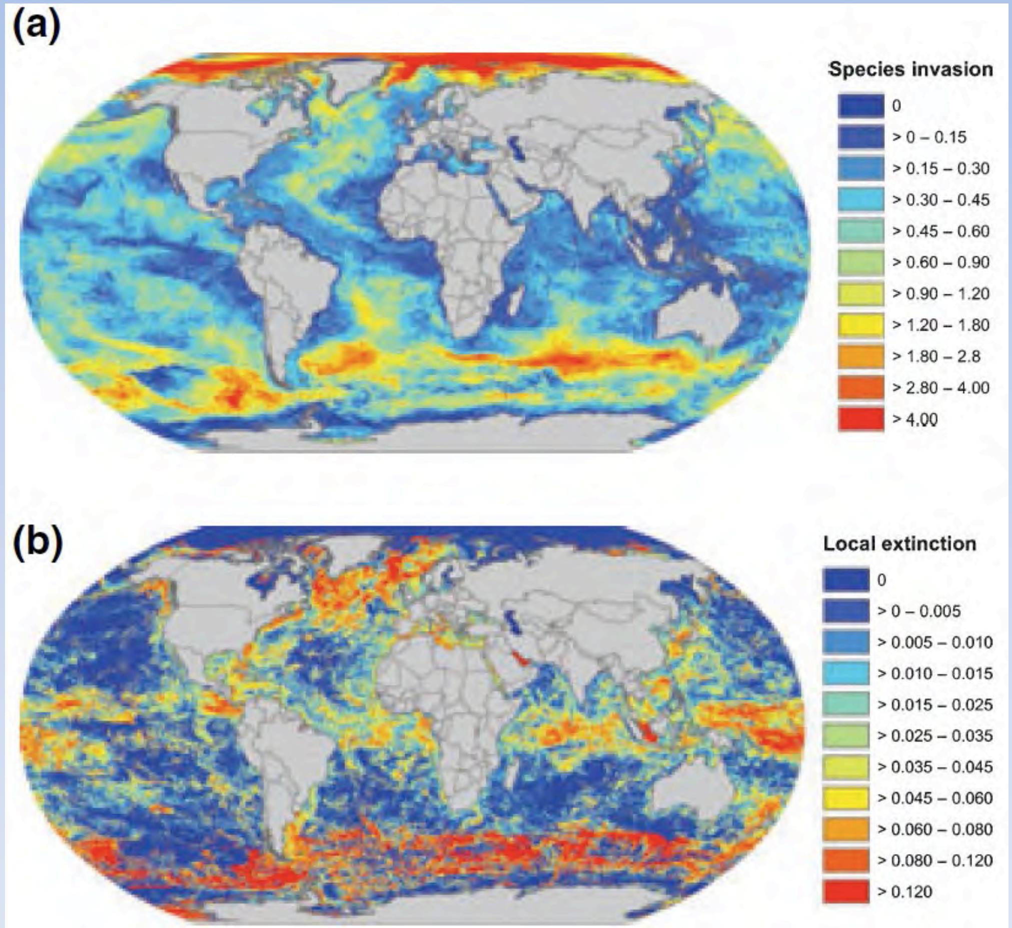
Invasions by 2050

species in 2001-2005

$N_{extinction}$=

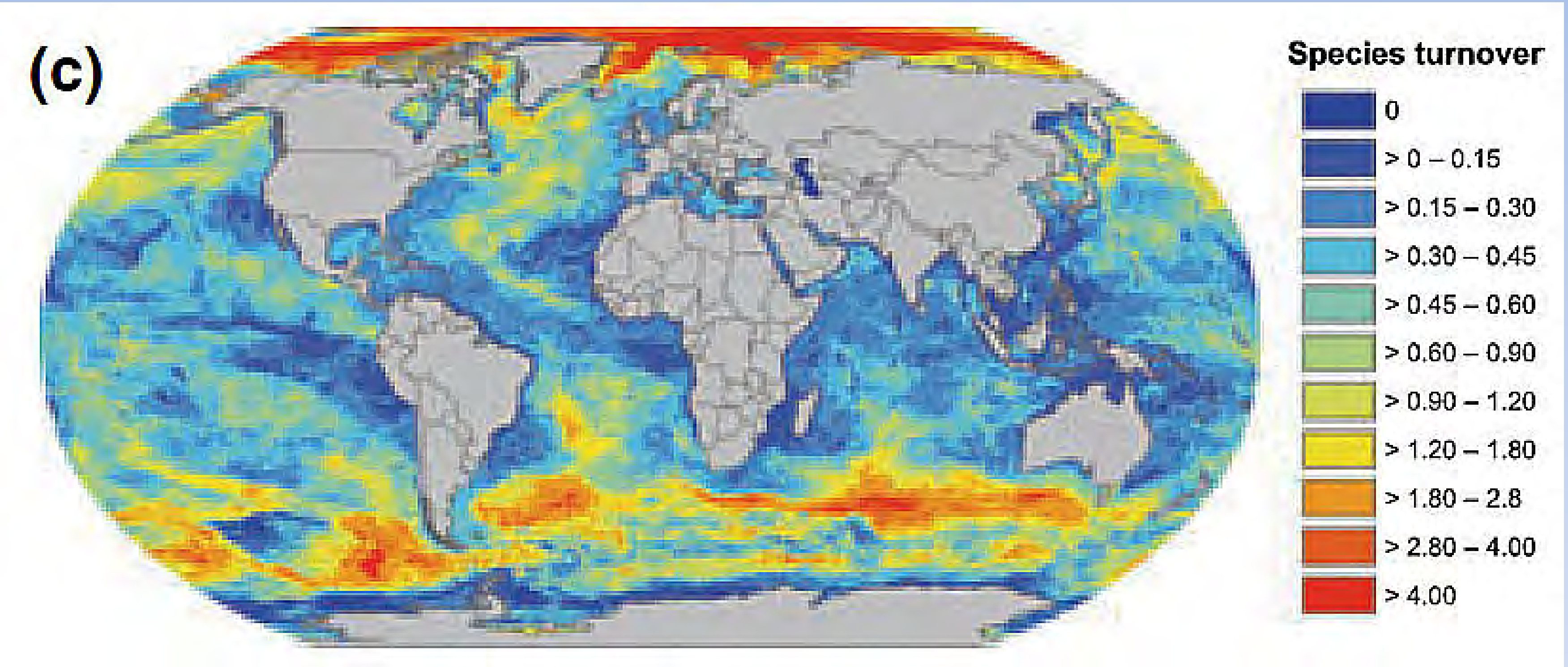
Extinctions by 2050

species in 2001-2005



Cheung et al. 2009

Predicted distribution of biodiversity impact due to warming-induced range shifts



Turnover = $| N_{invasion} - N_{extinction} |$

N=1066 species

Cheung et al. 2009

Projected change in catch potential by 2050 relative to 2000

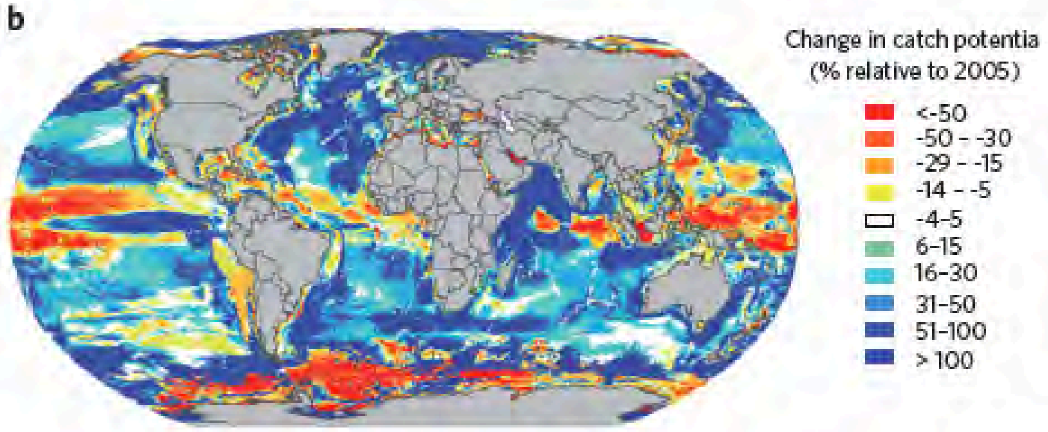
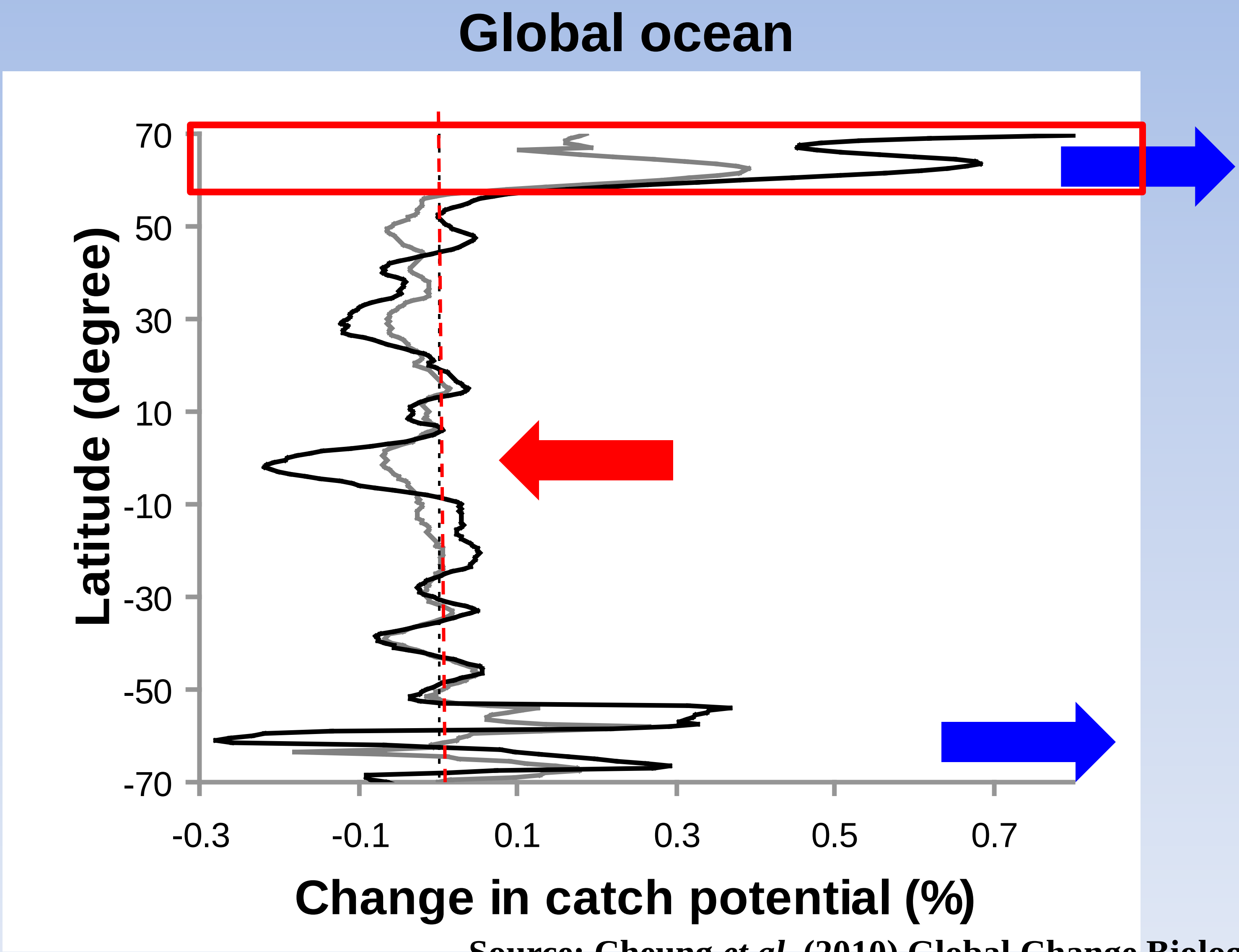


Figure 3 | Summary of the approach and key results of a modelling study that assesses the impacts of climate change on potential catches from global fisheries. a, First, by applying a spatial dynamic model (dynamic bioclimate envelope model) to 1,066 species of exploited fishes and invertebrates, future distributions of species under climate change are projected. Second, by combining these projections with projected primary productivity through an empirical model[58] and fisheries economic data, changes in future maximum potential catch and their economic implications are projected. **b**, Projected changes in maximum potential catch under the Intergovernmental Panel on Climate Change's A1B scenario. Reproduced with permission from ref. 12, © 2010 Wiley.

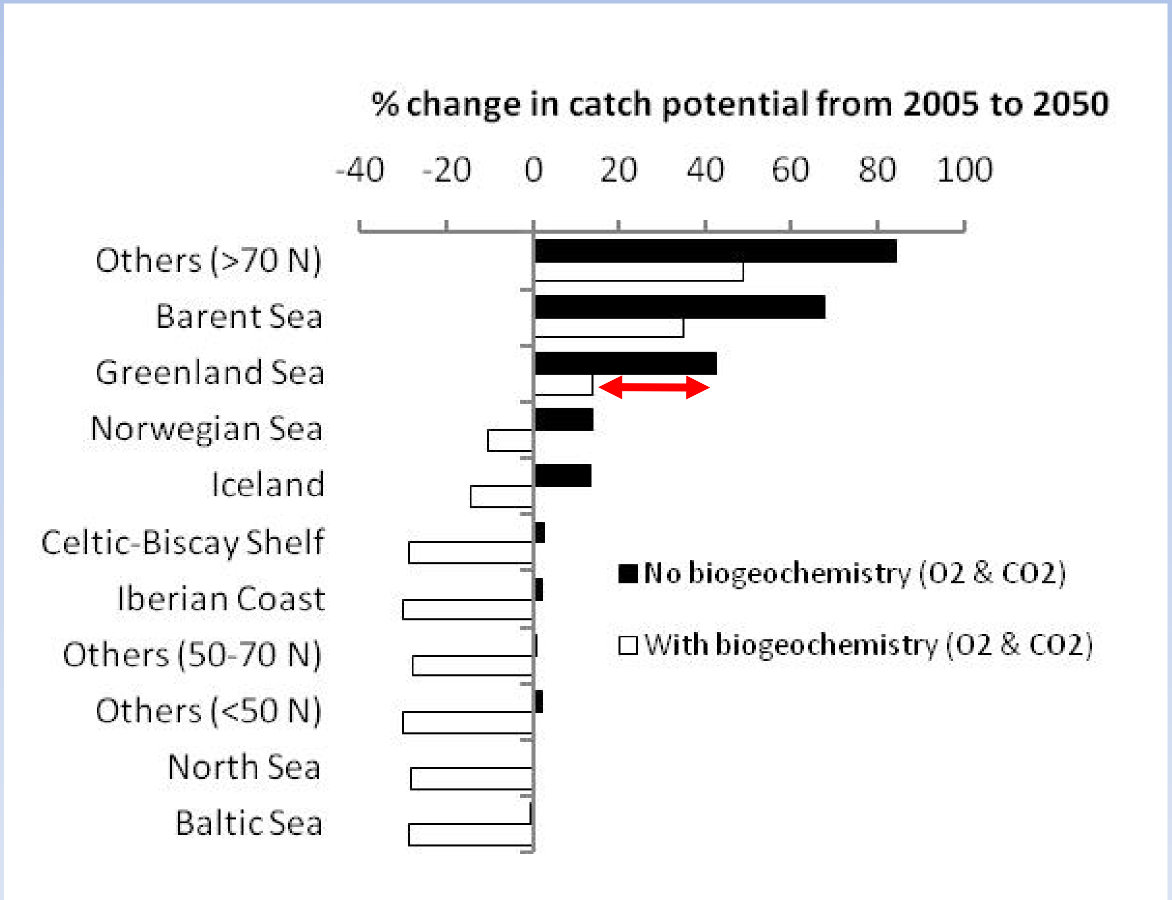
Sumaila et al., 2011 Nature climate change

Latitudinal average changes in potential catch



Source: Cheung *et al.* (2010) Global Change Biology

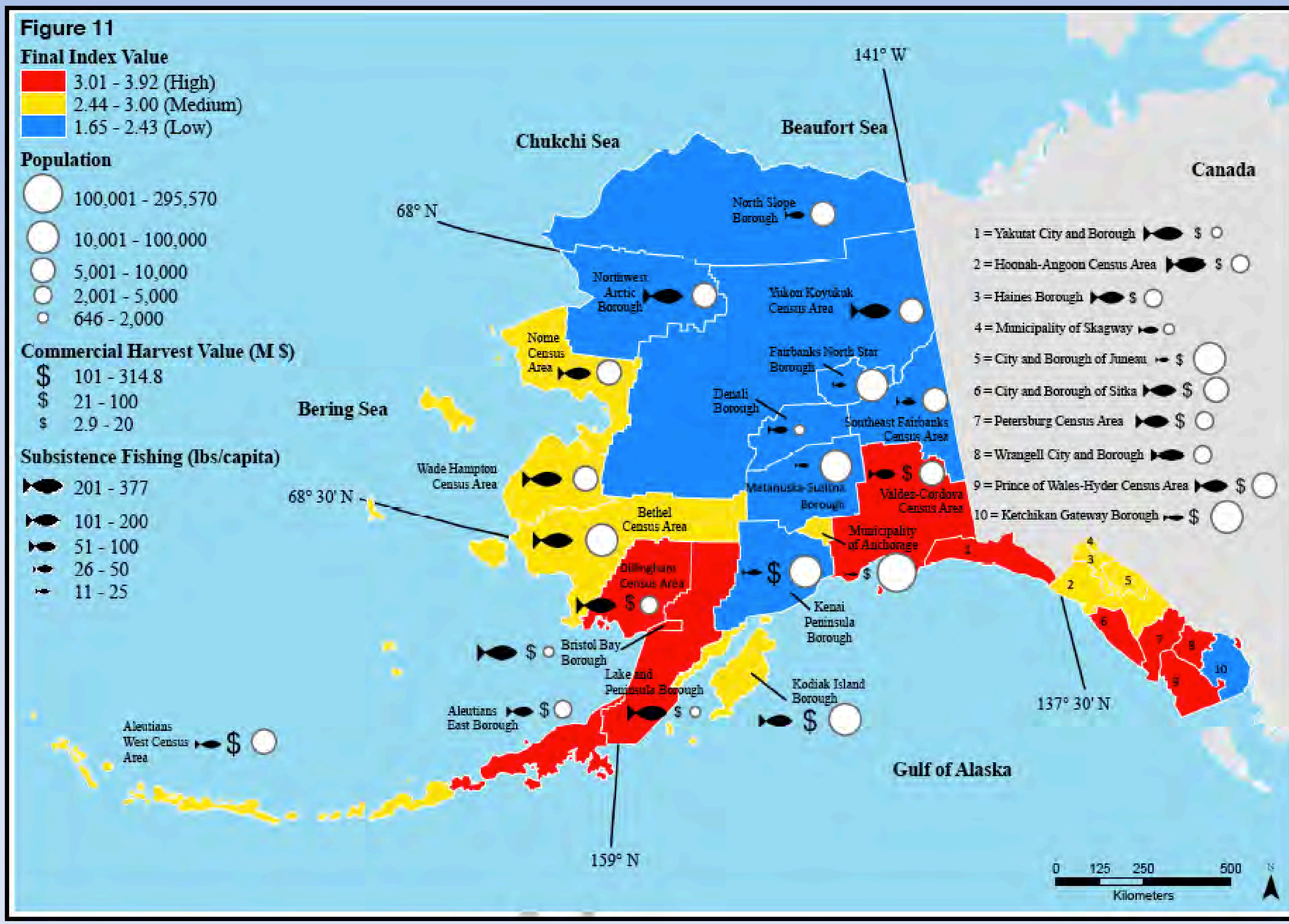
Effects of ocean acidification, oxygen content and phytoplankton community structure



- **Considerations of ocean chemistry leads to up to 20-35% additional reduction in maximum catch potential.**

Source: Cheung *et al*. (2011) ICES Journal of Marine Science

Alaskan Fishery may be challenged by OA



Mathis, J.T., Cooley, S.R., Lucey, N., Colt, S., Ekstrom, J., Hurst, T., Hauri, C., Evans, W., Cross, J.N., Feely, R.A., Ocean Acidification Risk Assessment for Alaska's Fishery Sector, *Progress in Oceanography* (2014), doi: http://dx.doi.org/10.1016/j.pocean.2014.07.001

The AMAP2 OA approach

- An assessment of new carbon cycle observations
- Coupling of OA and climate change to organism/ecological responses
- Develop an E2E approach from OA-ecosystem-economics
- Propagation to scenarios of whole system change
- Targeted workshops with stakeholders and experts in socio-economy.
- The Arctic in an earth system perspective
- An evaluation of Arctic Ocean services under OA

Thank you