OA as one of many issues: Overview of challenges to study compounded effects of multiple stressors

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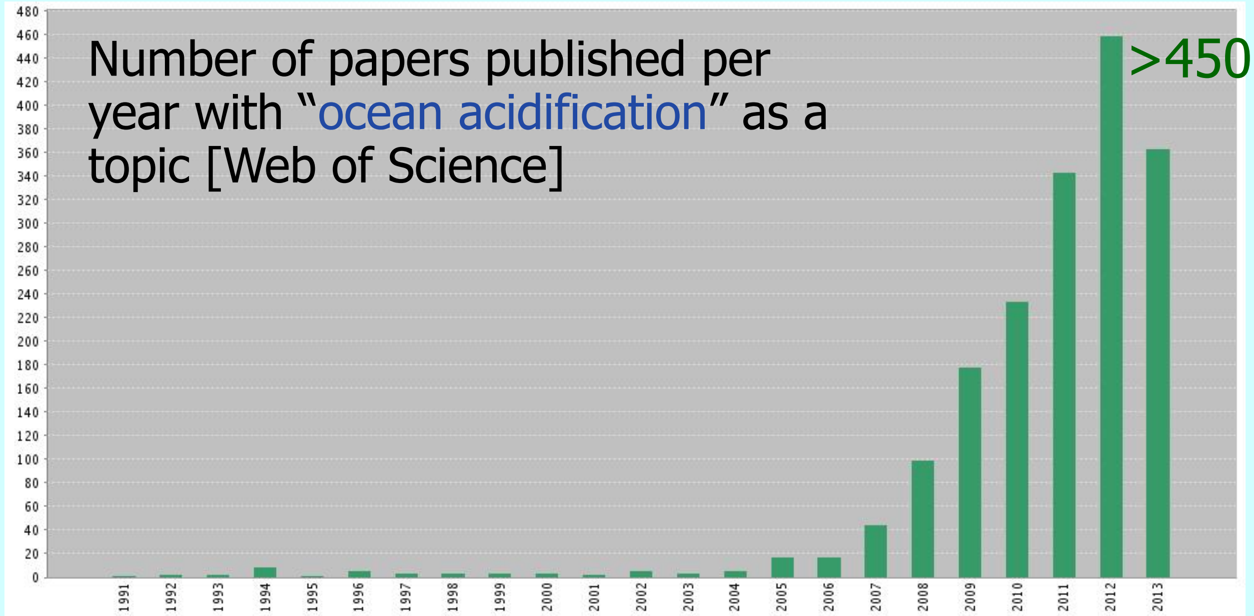
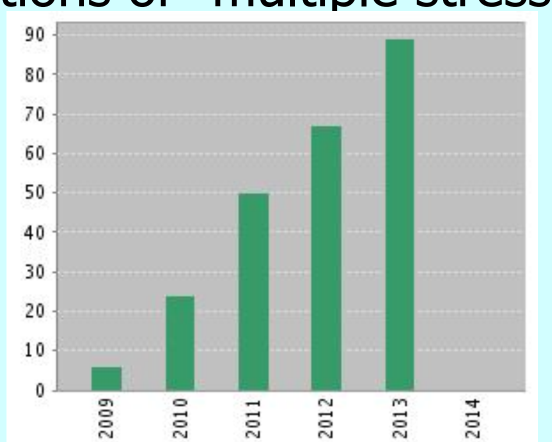
OA is a young and rapidly expanding field

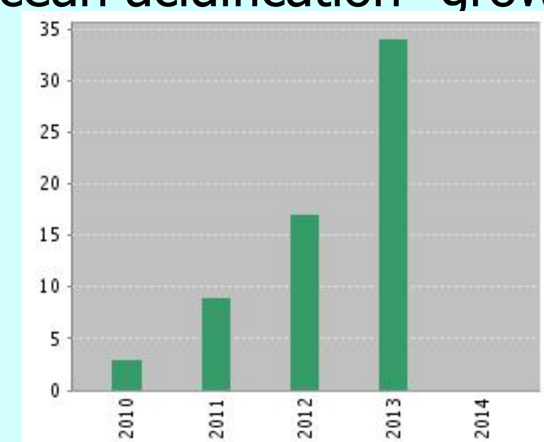


>450 publications last year

- OA effects investigated in combination with temperature / warming (2009 *MEPS*, PL Munday et al.; 2010 *MEPS*, H-O Pörtner)
- Citations of “multiple stressors” + “ocean acidification” growing quickly



Web of Science:
MS + OA as topics,
citations per year



Web of Science:
OA as title + MS as topic,
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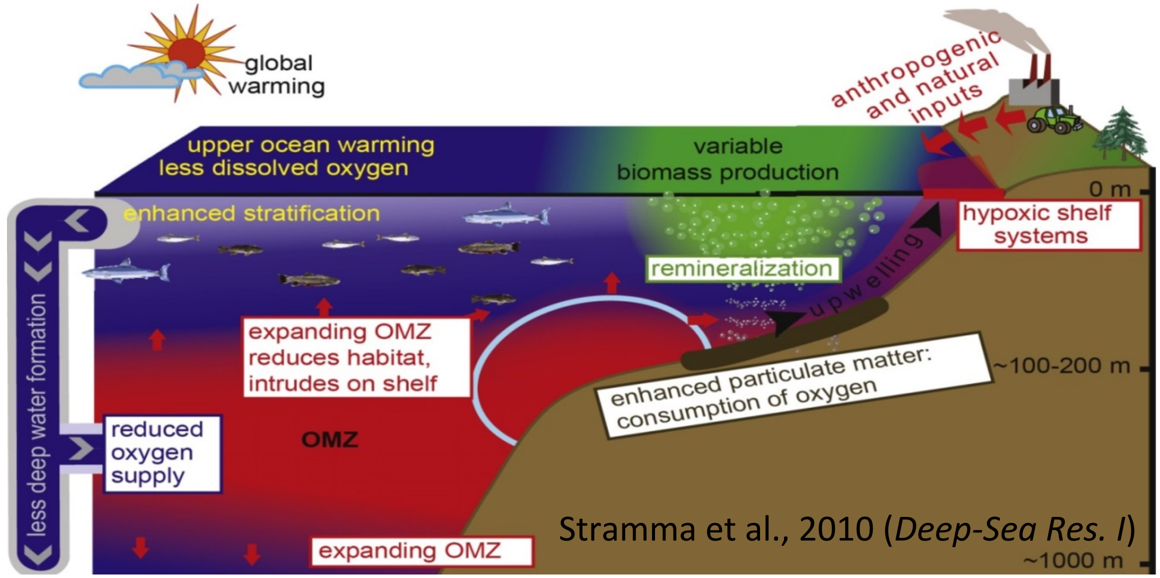
Many parameters are also changing in the oceans besides T and pH

- OMZs expanding (hypoxia)
- Eutrophication (nutrient loading)



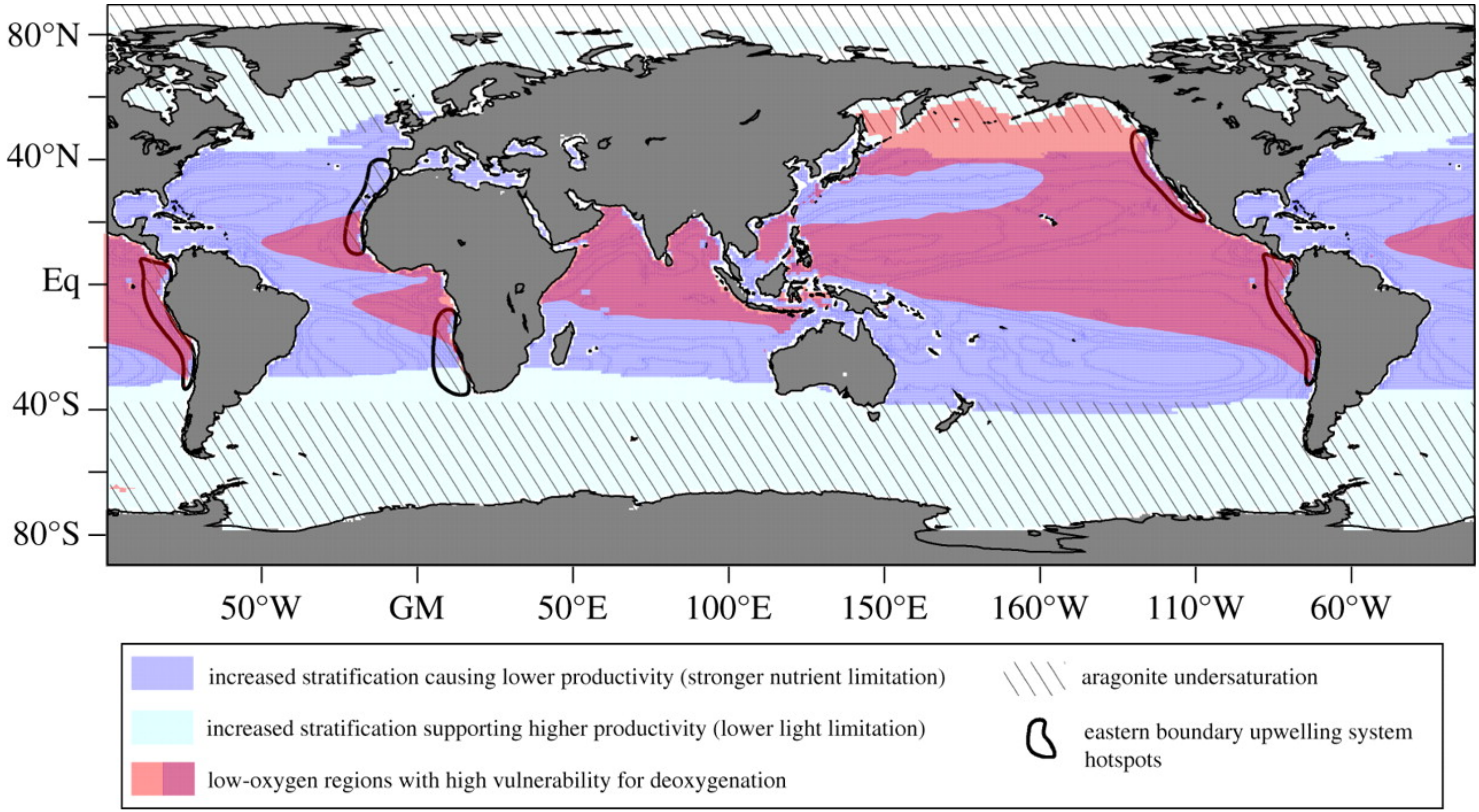
Stramma et al., 2010 (*Deep-Sea Res. I*)

- Anthropogenic changes (some more relevant to coastal &/or polar zones):
  - Acid rain, FW runoff, Herbi-/Pesticides, Heavy Metals, UV radiation (ozone)
  - Overfishing, urbanization, habitat destruction, human population growth

Another perspective: Processes driving changes in pH in marine ecosystems (Duarte et al. 2013 *Estuaries and Coasts*)

Driver	Pre-disturbance	Anthropogenic disturbance
Air–sea exchange	Air–sea CO_2 exchange	Ocean uptake of anthroporgenic CO_2
		Deposition of anthropogenic acids and bases
Watershed processes	Weathering	Mining
	Volcanic activity	Acid sulphate soil disturbance
	Ecosystem processes	Changes in land use
	Climatic variability	Agricultural practices
		Melting and thermokarst processes
		Hydrological perturbations
		Anthropogenic climate change
Ecosystem processes	Community metabolism	Eutrophication
	Mixing and water residence time	Habitat loss
		Anthropogenic climate change

Global map showing regions of particular vulnerability to three main stressors: ocean warming, acidification and deoxygenation



Gruber N *Phil. Trans. R. Soc. A (*2011) 369:1980-1996

New review: Capone & Hutchins (*Nature Geosci.*): Coastal upwelling microbial biogeochemistry in changing oceans

Special OA Issue of *Marine Biology* (August 2013) edited by Sam Dupont and Hans-O Pörtner; 37 contributions

- 90% lab perturbation experiments
- 83% are single-species experiments
- 93% shorter than 3 months (mean 49 days)
- 37% studied T and OA
- only 1 assessed 3 parameters (pH, T, nutrients; Troedsson *et al.*)

Mar Biol (2013) 160:2175–2187
DOI 10.1007/s00227-012-2137-9

ORIGINAL PAPER

Effects of ocean acidification, temperature and nutrient regimes on the appendicularian *Oikopleura dioica*: a mesocosm study

Christofer Troedsson · Jean-Marie Bouquet · Carla M. Lobon · Aliona Novac · Jens C. Nejstgaard · Sam Dupont · Suncica Bosak · Hans H. Jakobsen · Nadezda Romanova · Lene M. Pankoke · Alejandro Isla · Jörg Dutz · Andrey F. Sazhin · Eric M. Thompson

- Gelatinous zooplankton (+phytoplankton)
- Mesocosm (1.5-m ID), nested design without replication
- 2 levels of T, 2 levels of pCO_2, 3 levels of nutrient additions
- ~2.5 week duration

- Another recent publication regarding multiple stressors:

OPEN ACCESS Freely available online | PLOS ONE

Complex Responses of Intertidal Molluscan Embryos to a Warming and Acidifying Ocean in the Presence of UV Radiation

Andrew R. Davis[1*], Daniel Coleman[1], Allison Broad[1], Maria Byrne[2], Symon A. Dworjanyn[3], Rachel Przeslawski[1¤]

- OA, T (warming), UV radiation on Molluscan embryos
- Warming, to some threshold, may compensate for the effects of pH decline for some taxa. UV had mixed response

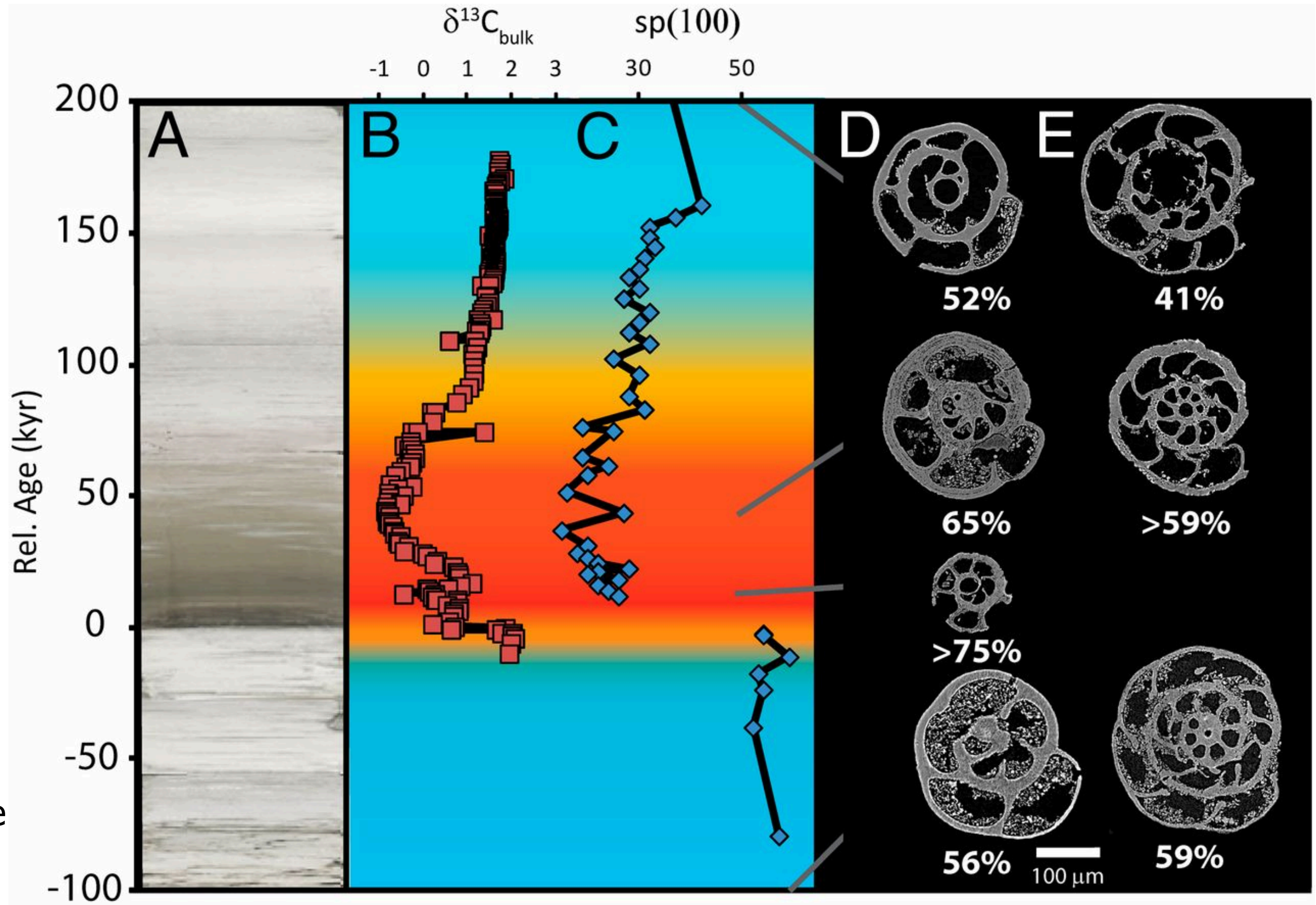
> - Results of multi-stressor papers imply complexities in responses (compounded effects of varied outcomes)
> - Obviously much to be learned in this context

- Problem is that testing multiple stressors can be space and resource intensive (lots of space, lots of time, lots of $$)
- Need clever approaches (especially if space, time, and funding are limited)

One clever approach is to use the fossil record:

- PETM (Paleocene Eocene Thermal Maximum; ~55 MYA): warming, deep-sea anoxia, inferred high pCO_2
- Foster et al. (2013 *PNAS*) assessed benthic foraminiferal test (shell) thickness across event
- Contrary to expectation, calcitic tests became more calcified (but not during maximum environmental perturbation, when they were "extinct")

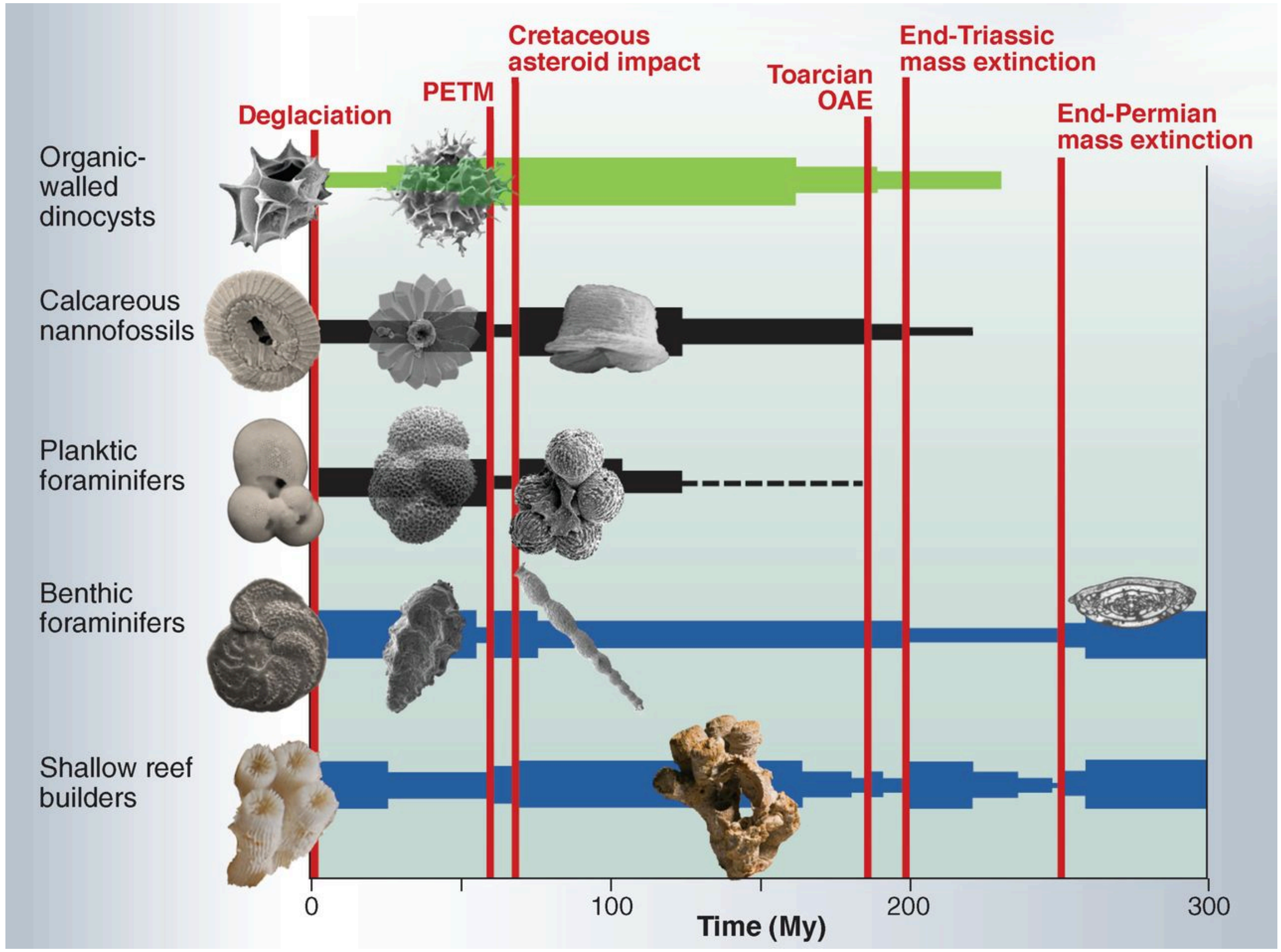
ODP site 1263 Walvis Ridge (A) digital core image with (B) $\delta^{13}C$ record (‰) and (C) rarefied number of species [sp(100)] plotted against numerical age from the onset of the PETM in thousands of years (kyr), (D) with tomographic reconstruction of cross-sections of *O. umbonatus* and (E) *N. truempyi*. The amount of calcite preserved is given relative to the test volume to correct for size effects. The color indicates temperature variation during the PETM, with temperature increasing from blue (cooler) to red (warmer) temperatures. The color of the sediments reflect $CaCO_3$ content, with darker colors indicating lower $CaCO_3$.



Foster L C et al. *PNAS* 2013;110:9273-9276

There may have been multiple OA events in the past, impacting multiple taxa:

Idealized diversity trajectories of calcareous and organic fossil lineages. Extinction & radiation suggest events of major environmental change during last 300 MY. Vertical red lines = potential OA events. Calcareous groups were not uniformly affected at all times suggesting importance of synergistic environmental factors to extinction, adaptation, and evolution and/or differing sensitivity to physiological factors.

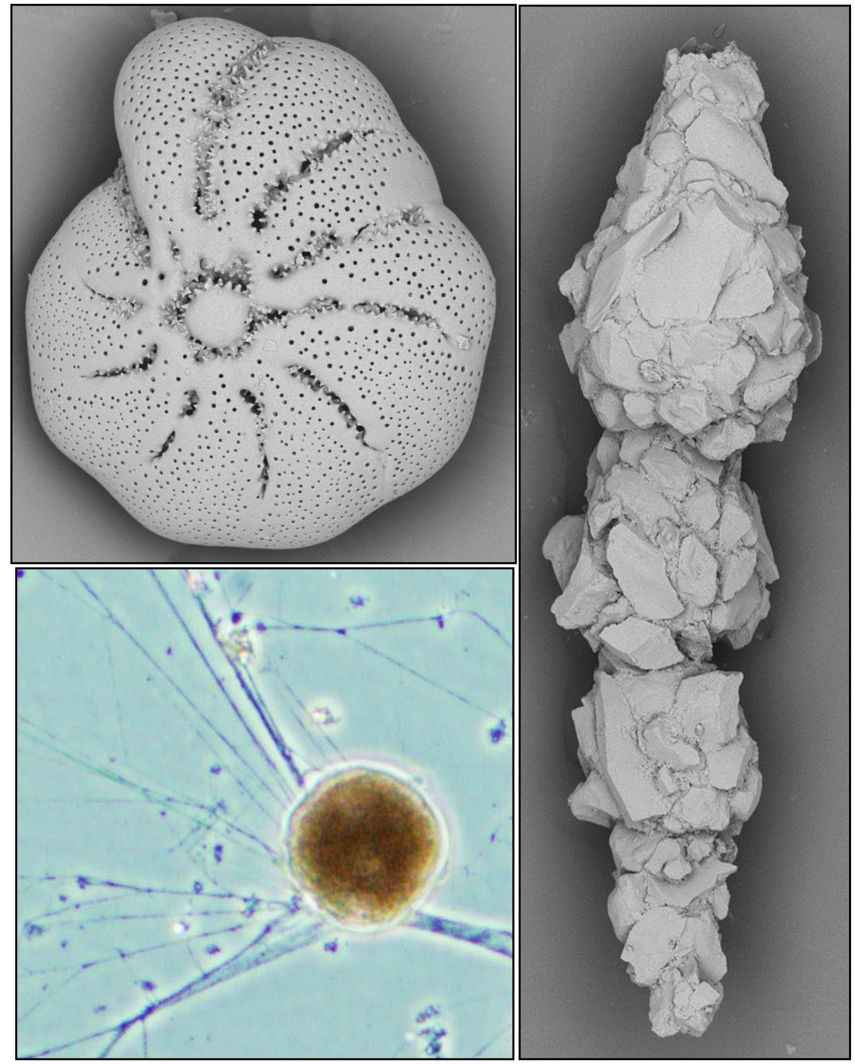


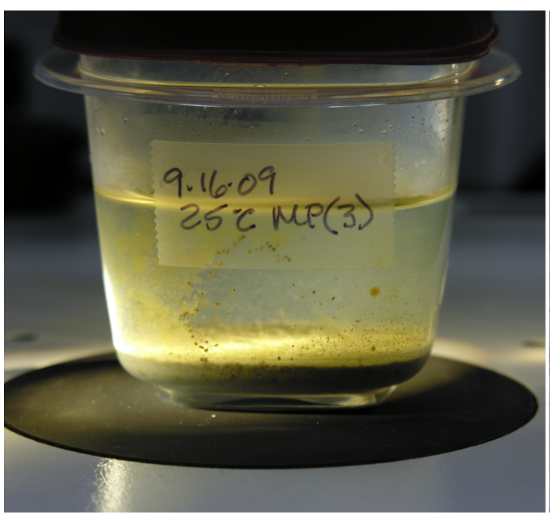
B Hönisch et al. *Science* 2012;335:1058-1063

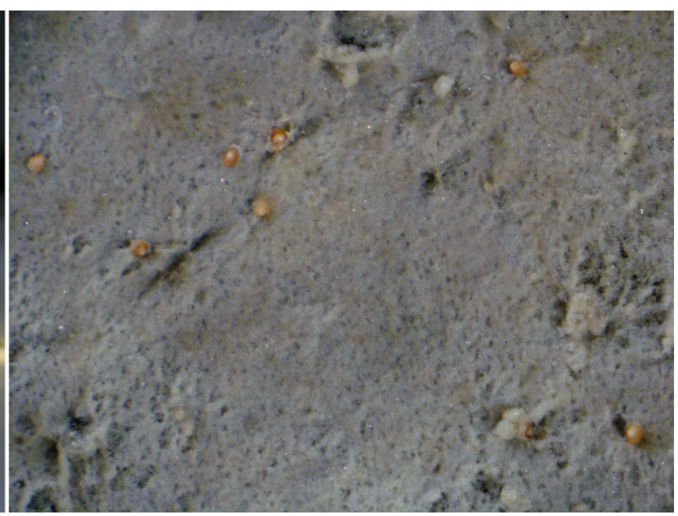
- Not all of these are good analogs to today's situation
- Rates of change in past not as fast as our modern-day changes

Another clever approach is being applied in my lab

- Long term (~8 month) experiment
- Varying O_2 and pCO_2, and later T (have means to pinpoint survival before and after T change)
- Unique in that:
  - Taxon (benthic foraminifera) has calcareous, agglutinated (non-calcareous) and non-mineralized representatives
  - 8 months is a significant period of life span
  - Some species known to be anaerobes
- Using relatively non-invasive protocol (only sieving, no advance picking)
- Relies on growth (must have grown during experiment)







Above: benthic foraminifera (calcareous, agglutinated, thecate [nonmineralized]); *Far left:* Example of "propagule" treatment (for a prior / different experiment); *Near left:* individual foraminifers grown during that experiment

Experiment Details

- Inoculum was <53 µm material, freshly collected from the seafloor (Most foraminiferal studies use a minimum sieve size of 63 µm)
- Using such fines relies on "propagules" (juvenile foraminifera) sensu Goldstein and Alve (2011 *MEPS*); CO_2 control McIntyre-Wressnig et al. 2012 *MEPS*

- Nested pCO_2 & O_2, at 7°C
- After ~6 months, will increase to 9°C
- Fluorogenic viability indicator will distinguish live from dead at termination; if present but dead, they likely died during warming

Treatment	Carbon dioxide (ppm)	Oxygen (ml/l)	Scenario
I	400	6.6	Present Day
II	400	0.7	Present Day hypoxia
III	2000	6.6	~2100 C.E.
IV	2000	0.7	~2100 C.E. hypoxia
V	275	6.6	Pre-Industrial (~1850 C.E.)

- Ability to compare present day *in situ* communities to those from pre-Industrial times using relict (neo-fossil) assemblages

Future Directions: (1) Analyze tests for geochemical proxies (e.g., B isotopes, B/Ca, potential redox proxies) [paleo-interpretations]; (2) assess gene expressions across treatments and by taxon (calcareous vs. agglutinated)

New Technical Abilities

Biogeosciences, 10, 5967–5975, 2013
www.biogeosciences.net/10/5967/2013/
doi:10.5194/bg-10-5967-2013

Biogeosciences Open Access

Technical Note: Controlled experimental aquarium system for multi-stressor investigation of carbonate chemistry, oxygen saturation, and temperature

E. E. Bockmon[1], C. A. Frieder[2], M. O. Navarro[2], L. A. White-Kershek[3], and A. G. Dickson[1]

MSEAS: Multiple Stressor Experimental Aquarium at Scripps

"flexibility for a wide range of treatment chemistry, seawater volumes, and study organisms"

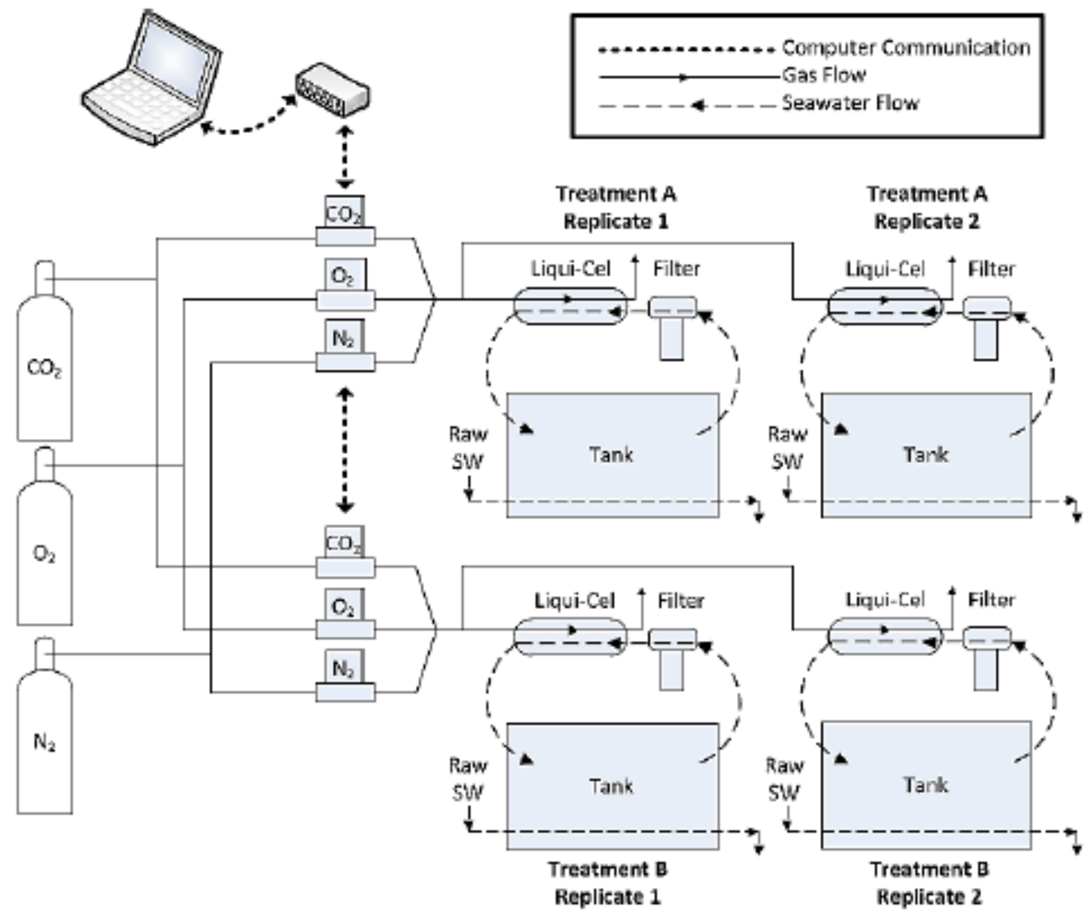


Fig. 2. Schematic of the aquarium control system. Solid lines indicate gas tubing and flow, and thin dashed lines indicate seawater tubing and flow. Thick dashed lines represent data communication between instruments.

What are the gaps?

- Facilities (like MSEAS, but even more parameters)
- Identifying attributes of natural variability (magnitude, duration, periodicity) and mimicking that in experiments
- Duration of experiments (need to span entire or multiple life spans)
- Will never be able to study each species, need to concentrate on taxa with varied physiologies
- Better integration of paleo-record with experimental results
- Funding – last OA call…