

PML

Plymouth Marine
Laboratory

A wide-angle photograph of an Arctic landscape. The foreground is filled with numerous icebergs of various sizes floating in dark blue water. In the background, a range of snow-capped mountains stretches across the horizon under a clear, bright blue sky. The overall scene is serene and cold.

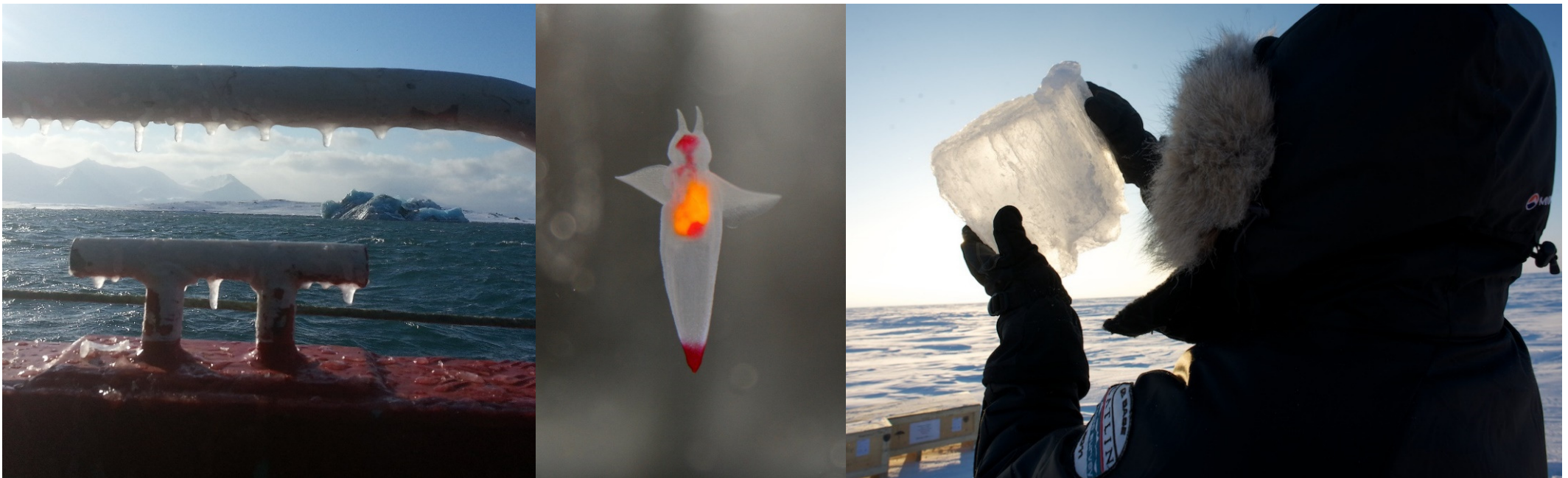
Ocean Acidification in the Arctic

Helen Findlay

Current research

- State-of-the-art: OA studies on Arctic species, communities & ecosystems
- Variable environments: mobility and hydrodynamics; using other tools to infer species/ecosystem sensitivity
- Making inferences from lower latitude studies

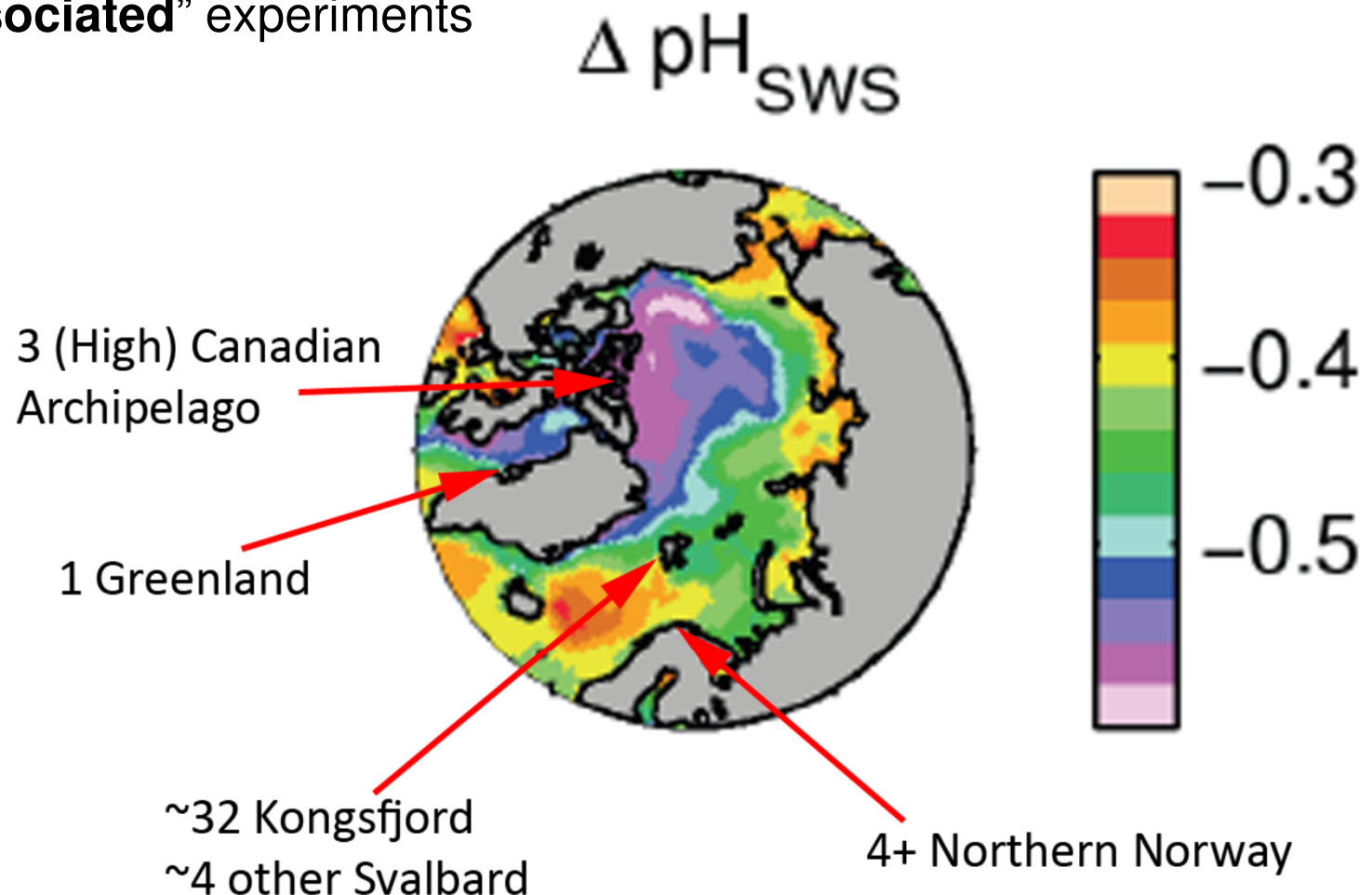
Research priorities



~**50 Arctic-specific OA studies** (either specifically investigate the impact of OA on biology/biogeochemistry or infer impacts from observations)

~**6 different locations**

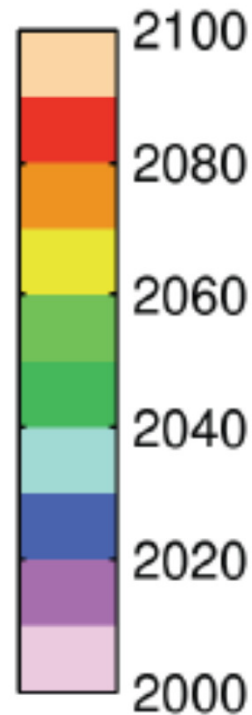
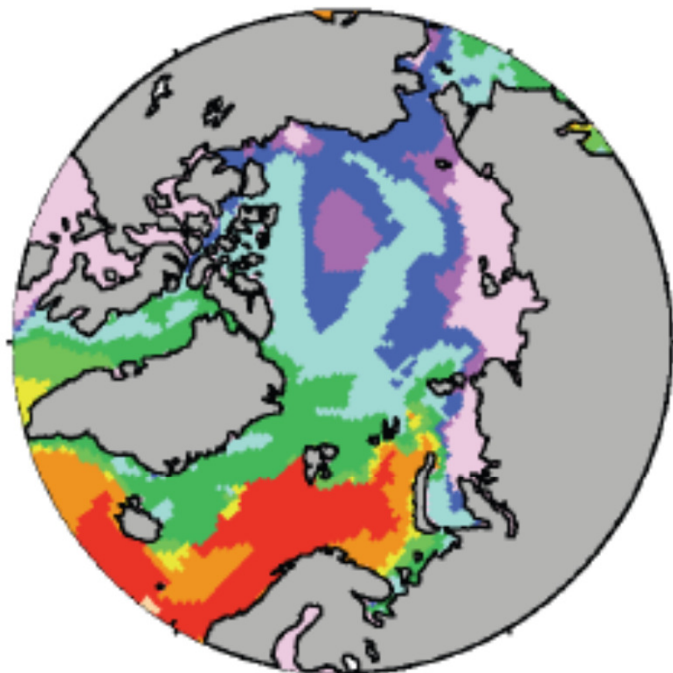
~2 sets of “**ice-associated**” experiments



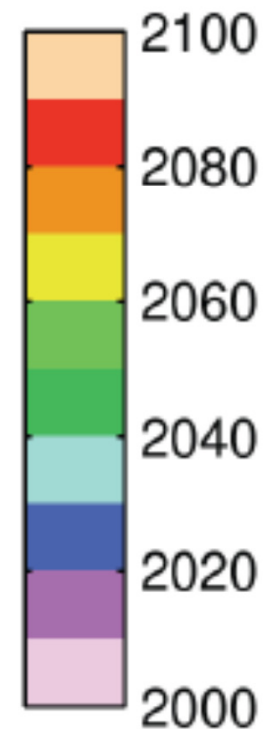
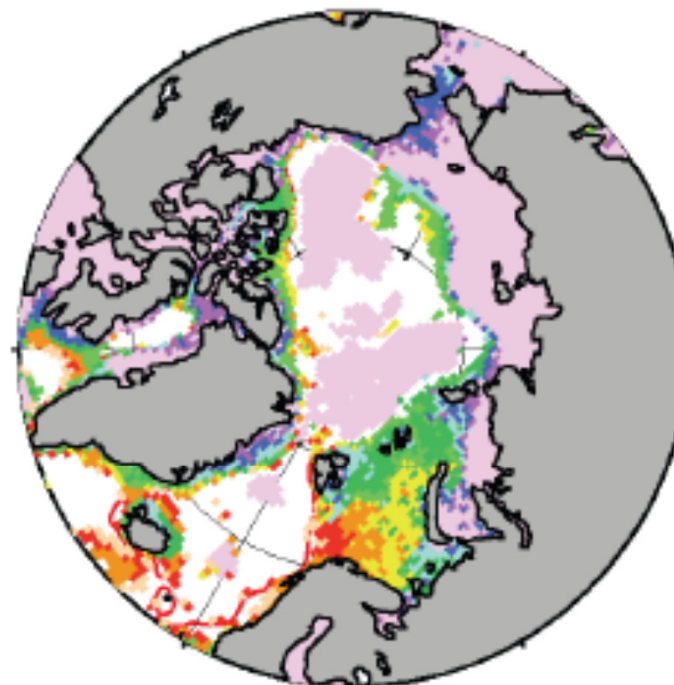
Are we looking in the **right places**? Or are they just the “**easy**” places?

Popova et al. 2014 **Model projections**: Year of the first occurrence of monthly mean aragonite undersaturated waters occur.

Surface waters



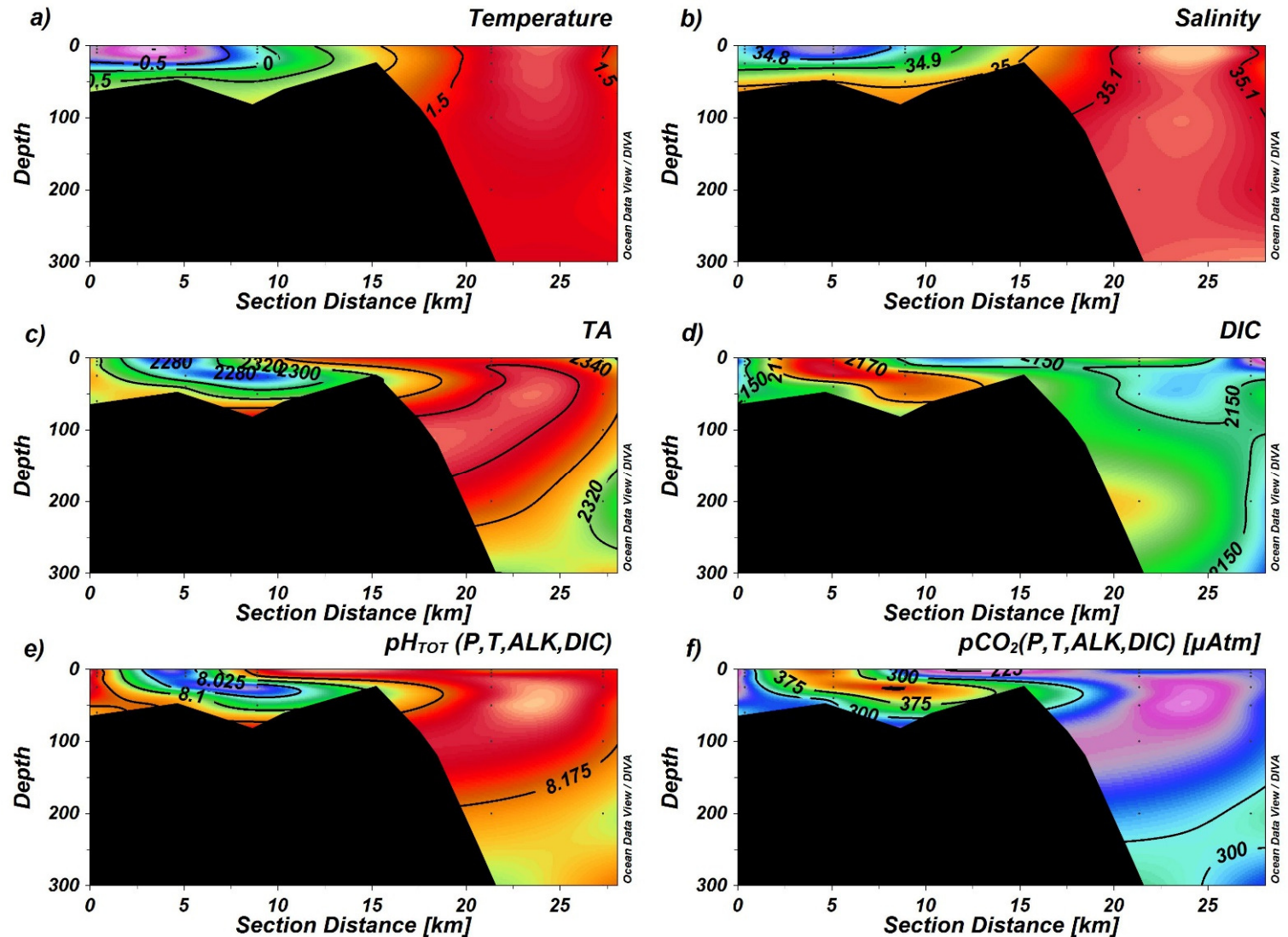
Bottom waters



Are we **exposing** them to the ‘right’ conditions? Or are they **already** exposed?

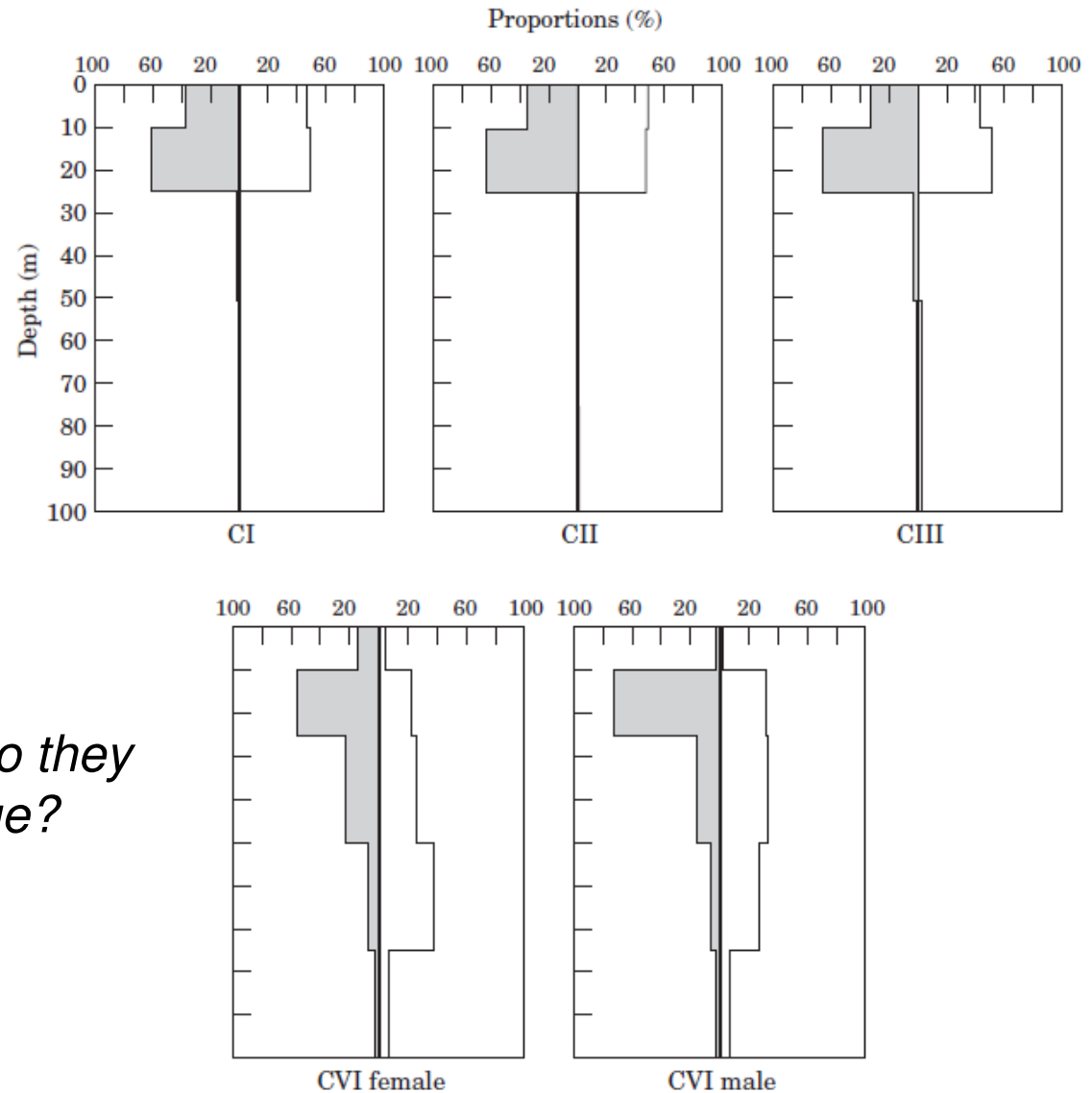
Kongsfjord: April 2014

Spatial range:
 Temperature ~2 oC
 Salinity ~0.5
 pH 0.3 units



Zooplankton, including copepods, often **undergo DVM**

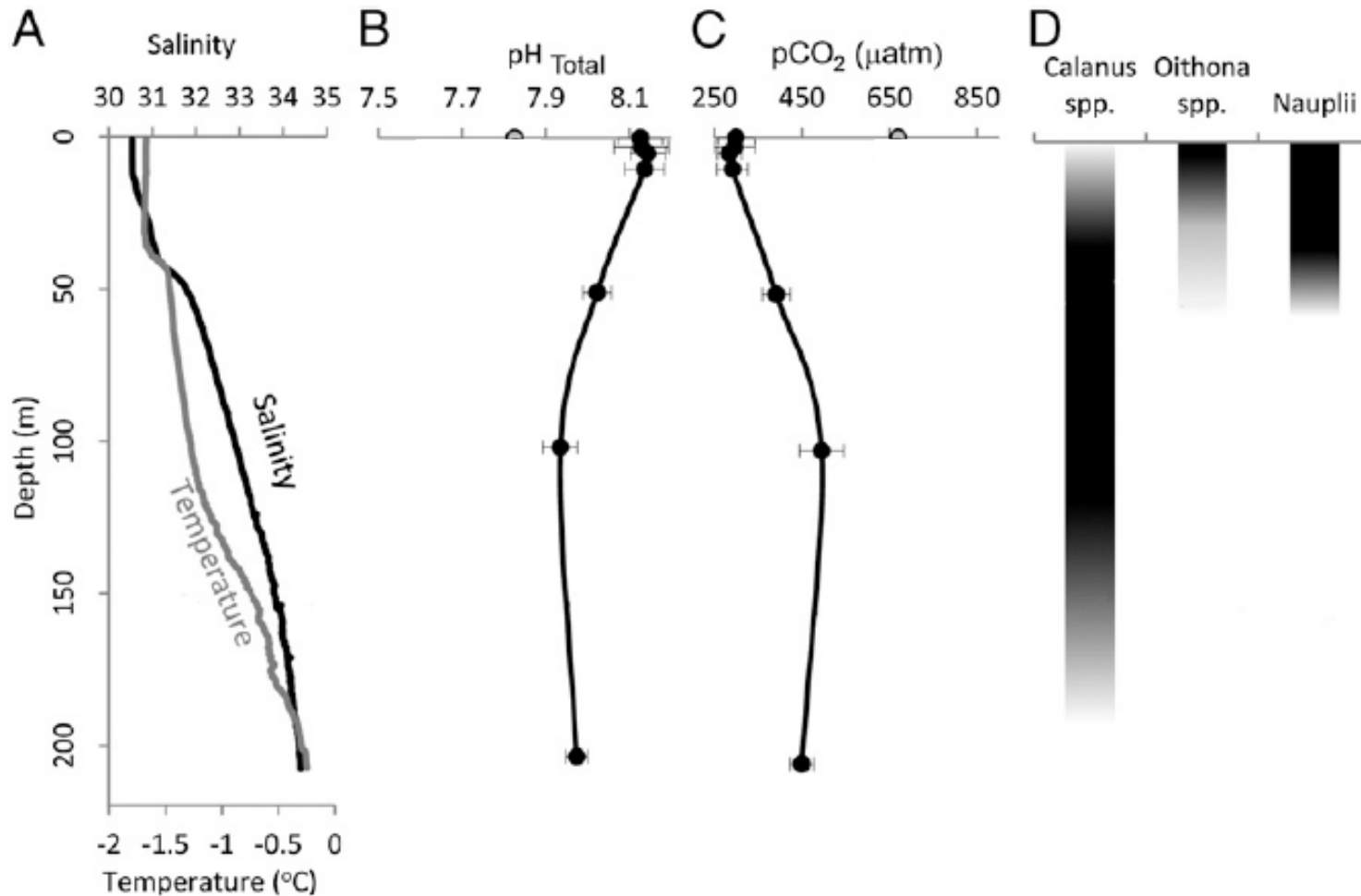
- **Life-stage** dependent
- **Seasonal** dependent



What environmental conditions do they experience over this vertical range?

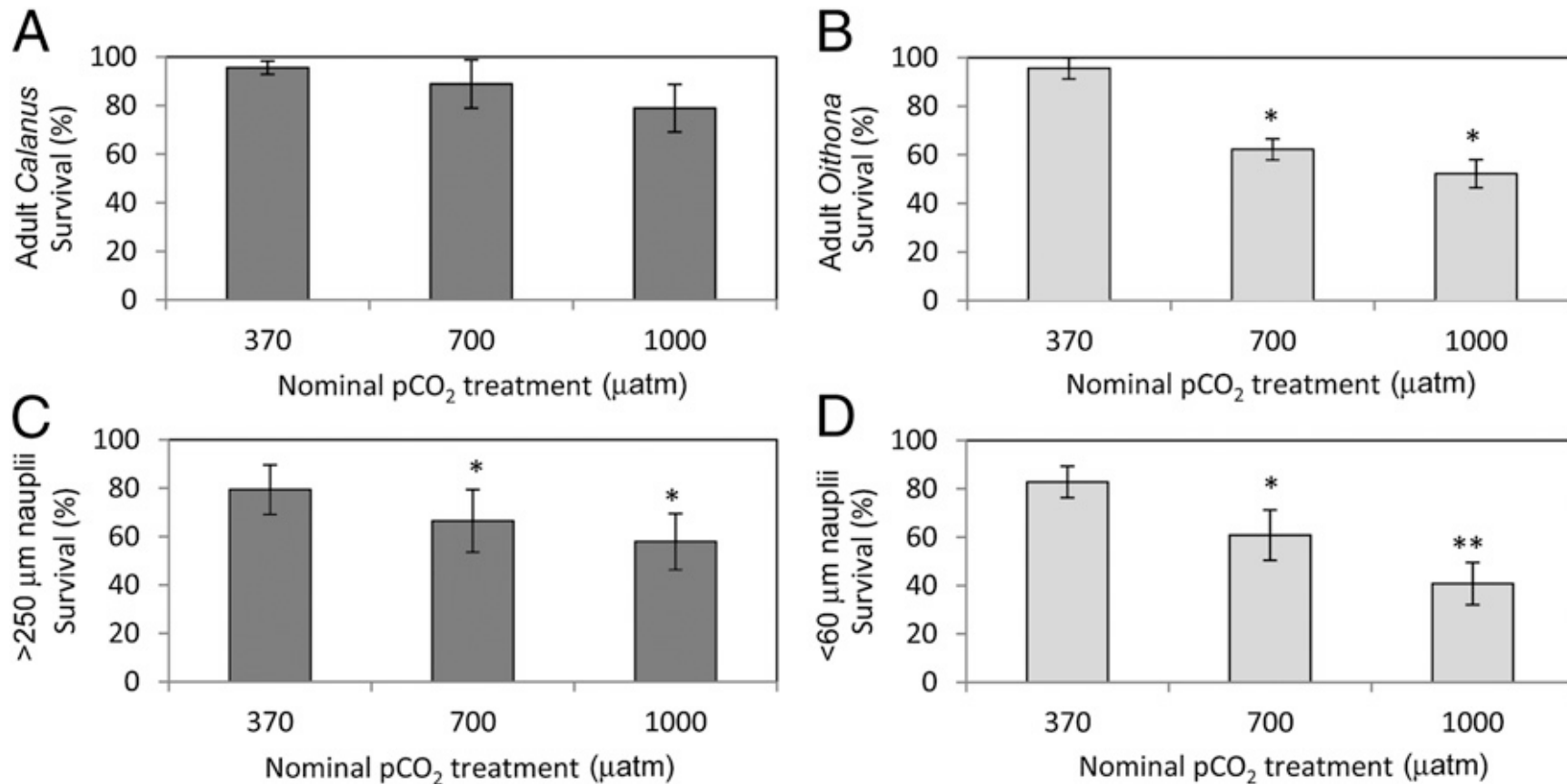
Non-migratory organisms are **confined to specific conditions**

Migrators **cross gradients** of environmental factors: temperature, salinity, pH and pCO₂



Copepods **sensitivity** in short-term OA experiments **reflects their DVM patterns**:

- Large **migratory** adult *Calanus* were **least sensitive**
- Small **non-migratory** adult *Oithona* and nauplii of both spp. were **most sensitive**



Patterns are reflected in the **wider copepod literature...**

Author	Species	pH range	Sensitivity to year 2100 level					Adult DVM?	
			EP	H	N	C	Adult		
This study	<i>Calanus glacialis/hyperborealis</i>	8.04–7.60			√		x	Hays (51), Falk-Petersen et al. (52)	√
This study	<i>Oithona similis</i>	8.04–7.60			√		√	Coyle and Pinchuk (53)	x
Weydmann et al. (54)	<i>Calanus glacialis</i>	8.20–6.90	x					Falk-Petersen et al. (55)	√
Fitzer et al. (56)	<i>Tisbe battagliai</i>	8.06–7.67			√	√	√	Hicks and Coull (57)	x
Kurihara and Ishmatsu (58)	<i>Acartia tsuensis</i>	8.23–7.31*	x	x	x	x	x	Sakaguchi et al. (59)	?
Kurihara et al. (60)	<i>Acartia steueri</i>	8.09–6.82*	x				x	No data	?
Kurihara et al. (60)	<i>Acartia erythraea</i>	8.09–6.82*	x	x	x		x	Tang et al. (61)	√
Vehmaa et al. (62)	<i>Acartia bilifosa</i>	8.17–7.77	x					White et al. (63)	√
Li and Gao (64)	<i>Centropages tenuiremis</i>	8.18–7.83					†	Boyd et al. (65)	√
Mayor et al. (66)	<i>Calanus helgolandicus</i>	8.08–7.77	x	x				Williams (67)	√
McConville et al. (68)	<i>Centropages typicus</i>	8.04–7.78	x	x				White et al. (63)	√
McConville et al. (68)	<i>Temora longicornis</i>	8.04–7.78	x	x				Harding et al. (69)	√
Pedersen et al. (70)	<i>Calanus finmarchicus</i>	8.20–6.85*		x	x	x		Falkenhaus et al. (71)	√

C, copepodite stages; EP, egg production; H, hatching; N, nauplii stages; x, no response to OA or does not exhibit diel vertical migration (DVM); √, response to OA or does exhibit DVM; ?, no data available.

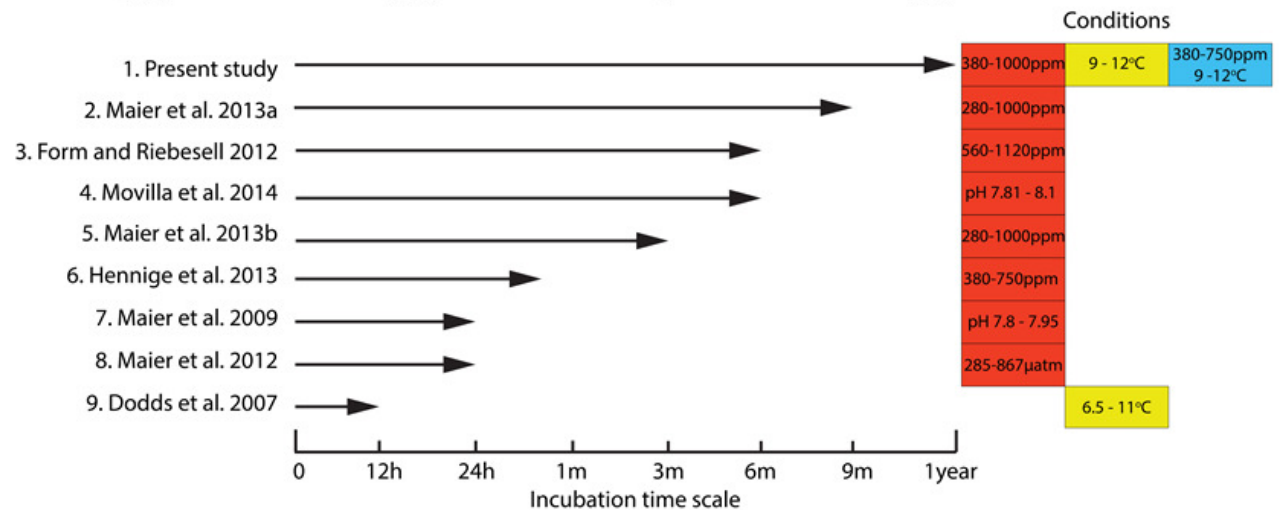
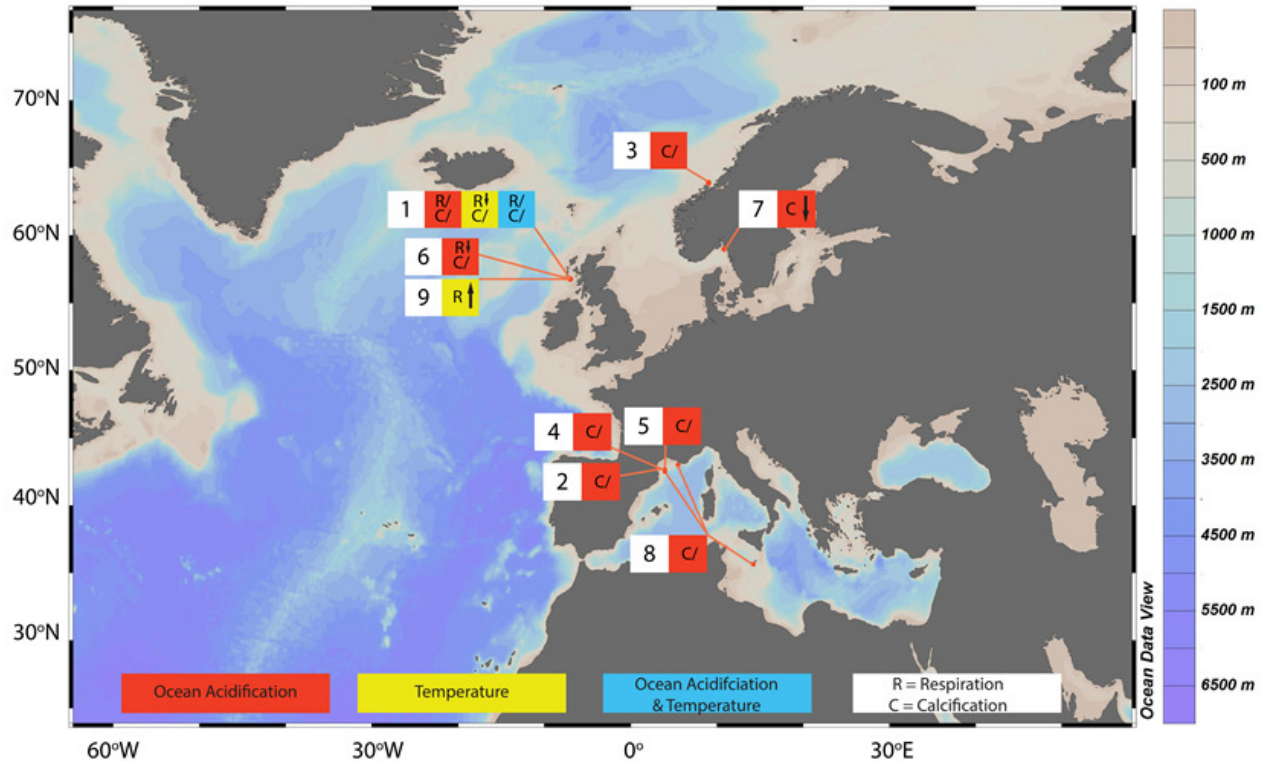
*No year 2100 pCO₂ scenario was used in the cited experiment; however, no response was recorded for the more extreme experimental pCO₂ scenario.

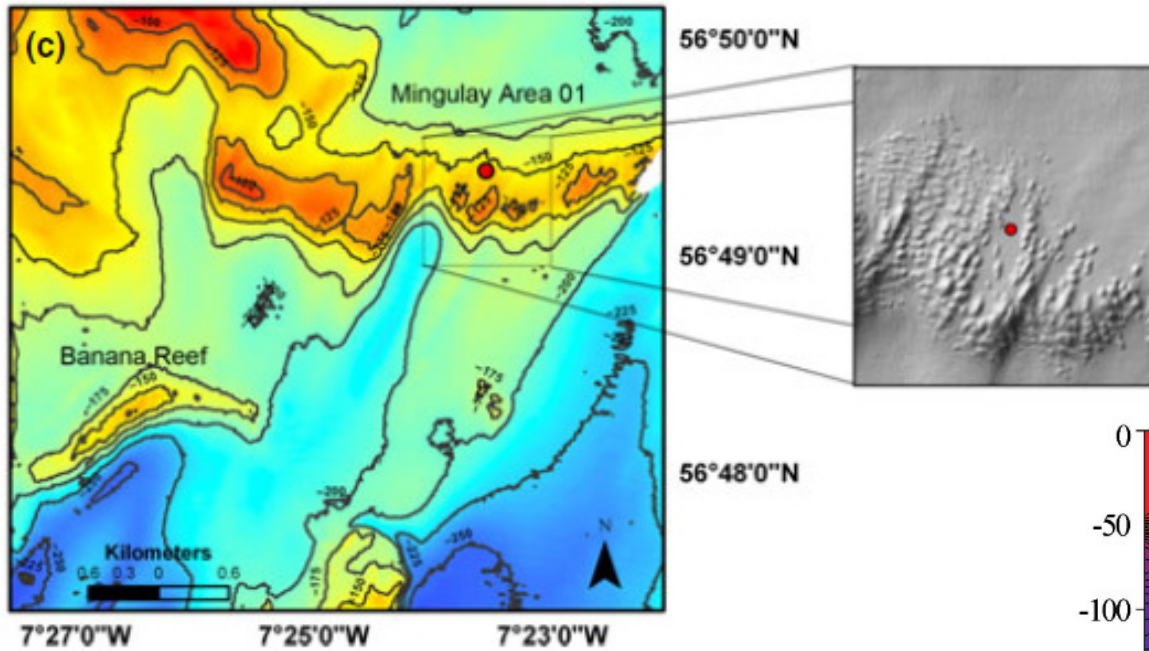
†Physiological adjustment to conditions was observed, but no clear negative health impact was associated with this change.

...and similar results for have been found for **pteropods!**

- Variable response to OA and temperature
- Calcification 'in general' shows no sig. response or decrease
- Respiration changes with temperature
- Links with energy budget

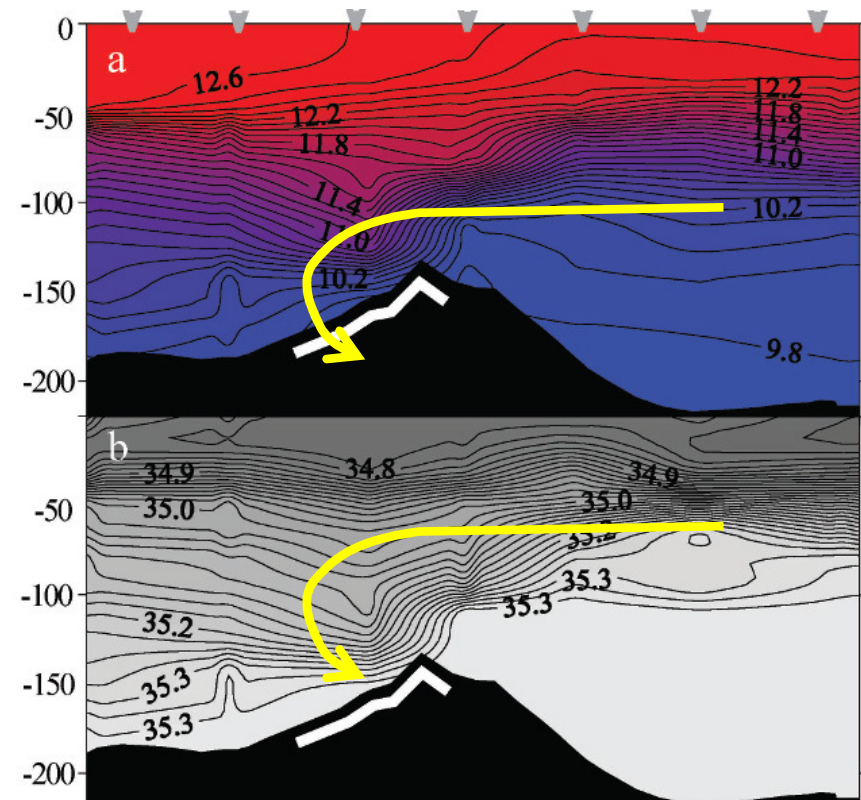
What do they naturally experience?



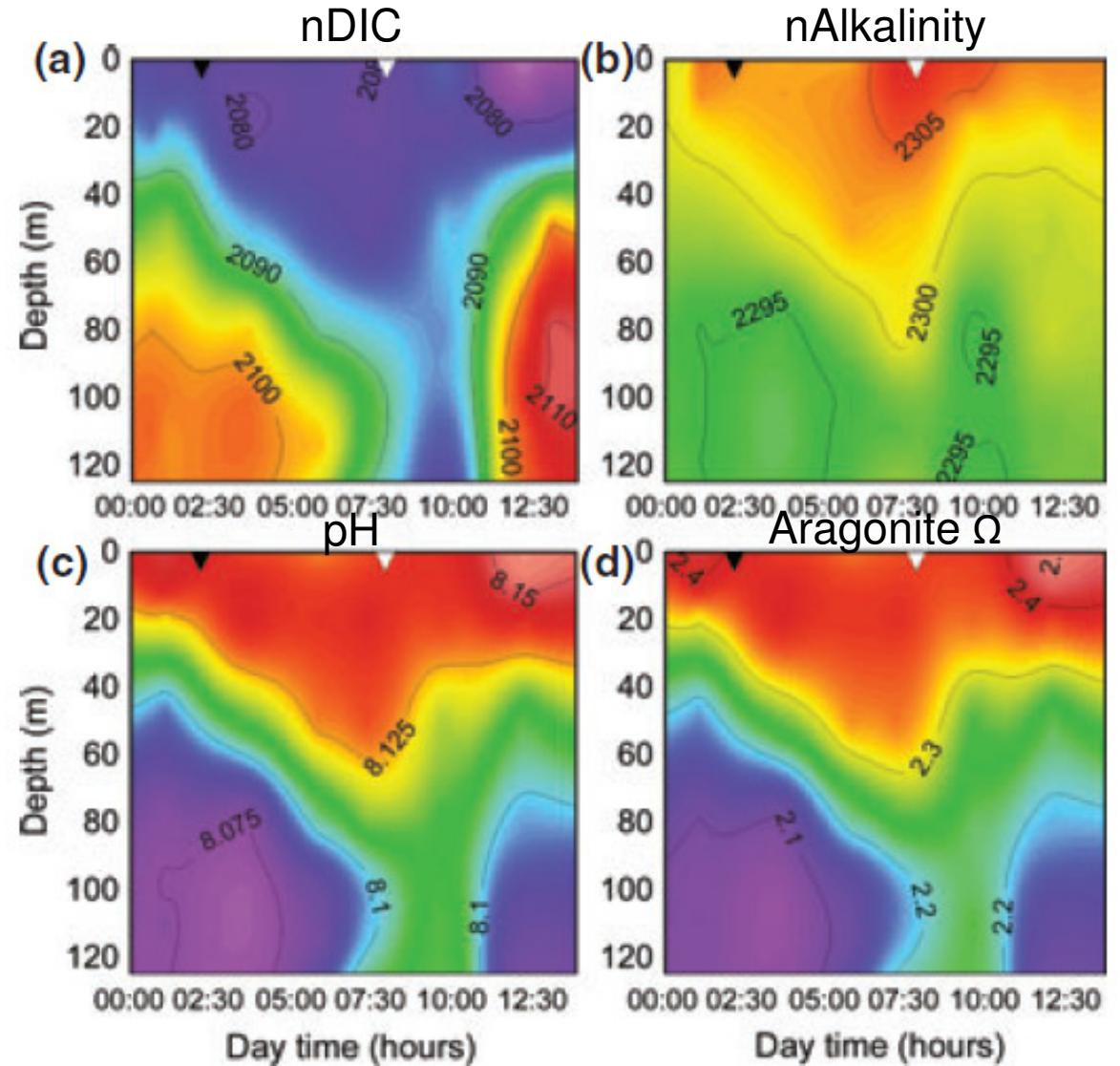


Mingulay reef (off Scotland)

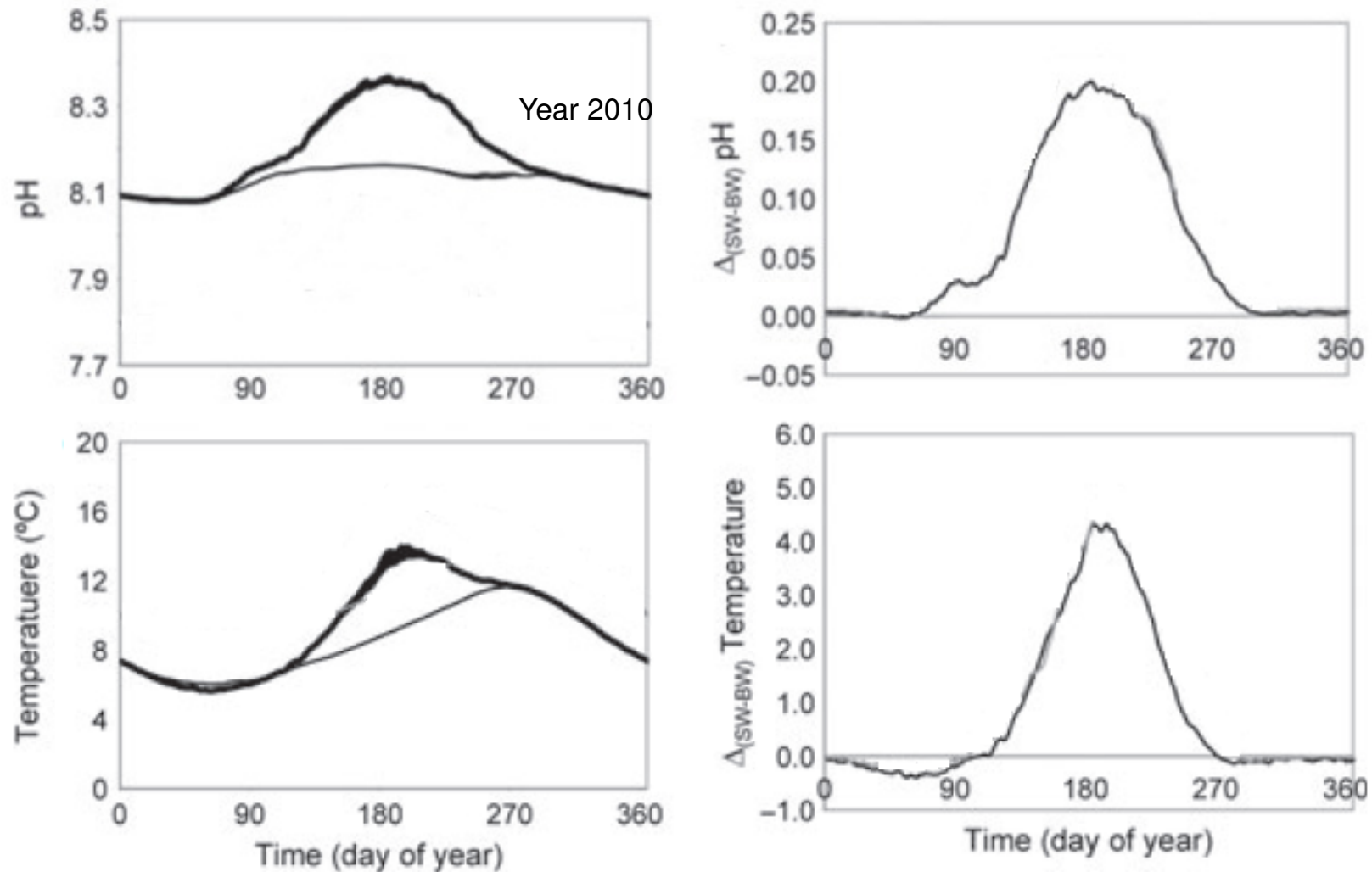
- Corals grow on one side of the 'mounds'
- Mounds, together with tides, create a very dynamic system
- **Tidally-driven downwelling** of surface waters



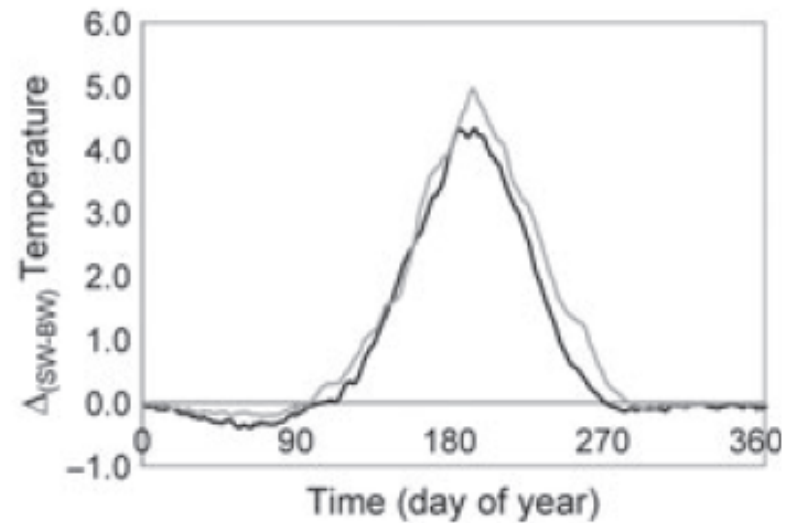
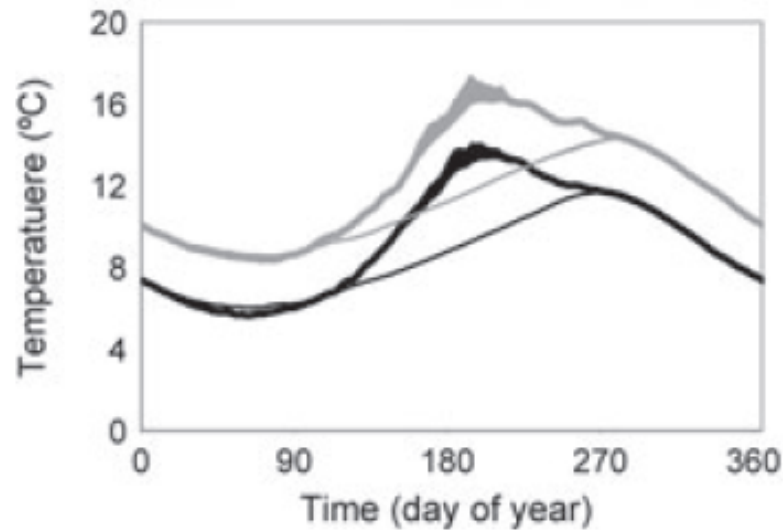
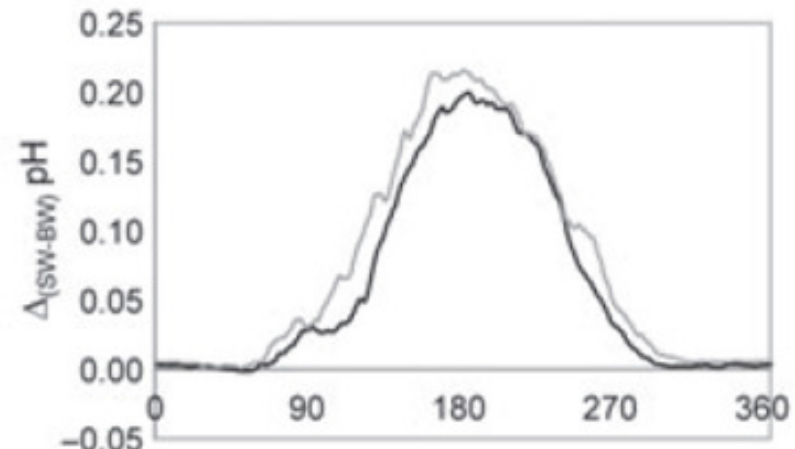
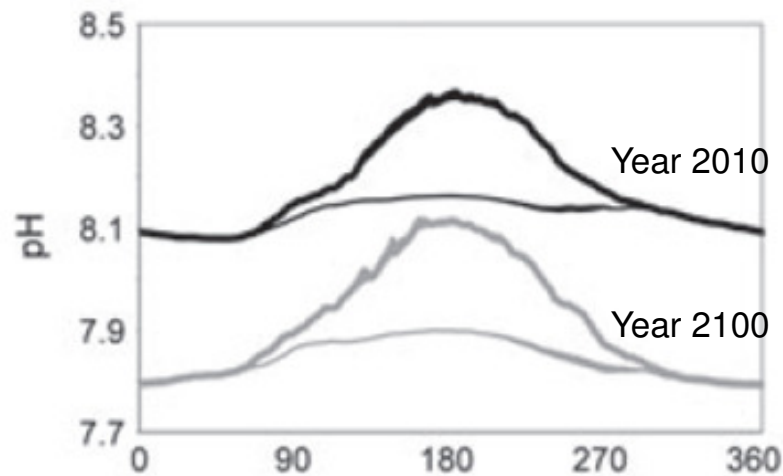
- pH highest in surface waters – associated with phytoplankton
- pH at reef depth ~8.04, but increased over tidal cycle with downwelling to ~8.12.
- Aragonite Ω ranged from ~2.1 to ~2.3



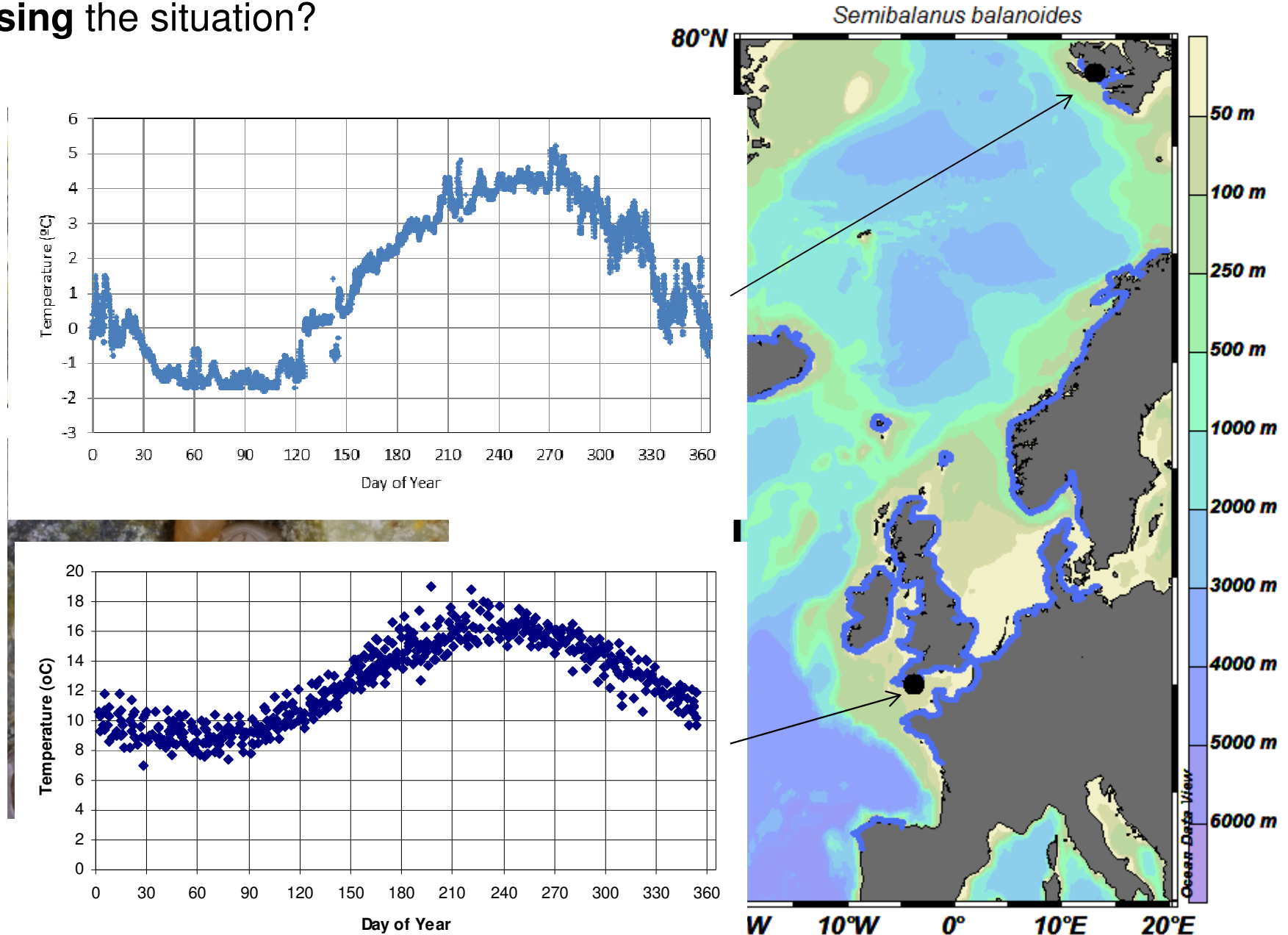
Are we making the right **inferences**? Or will they respond to other **factors**?



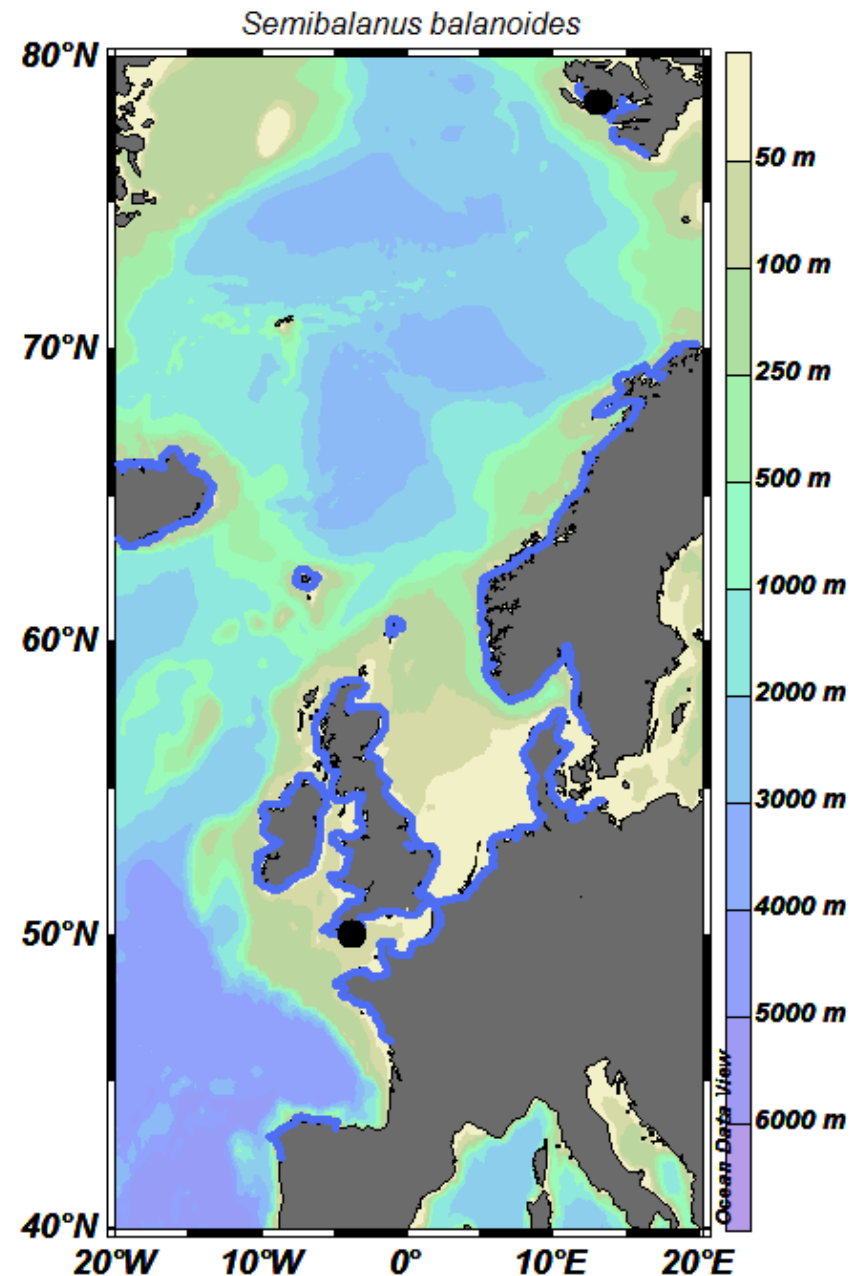
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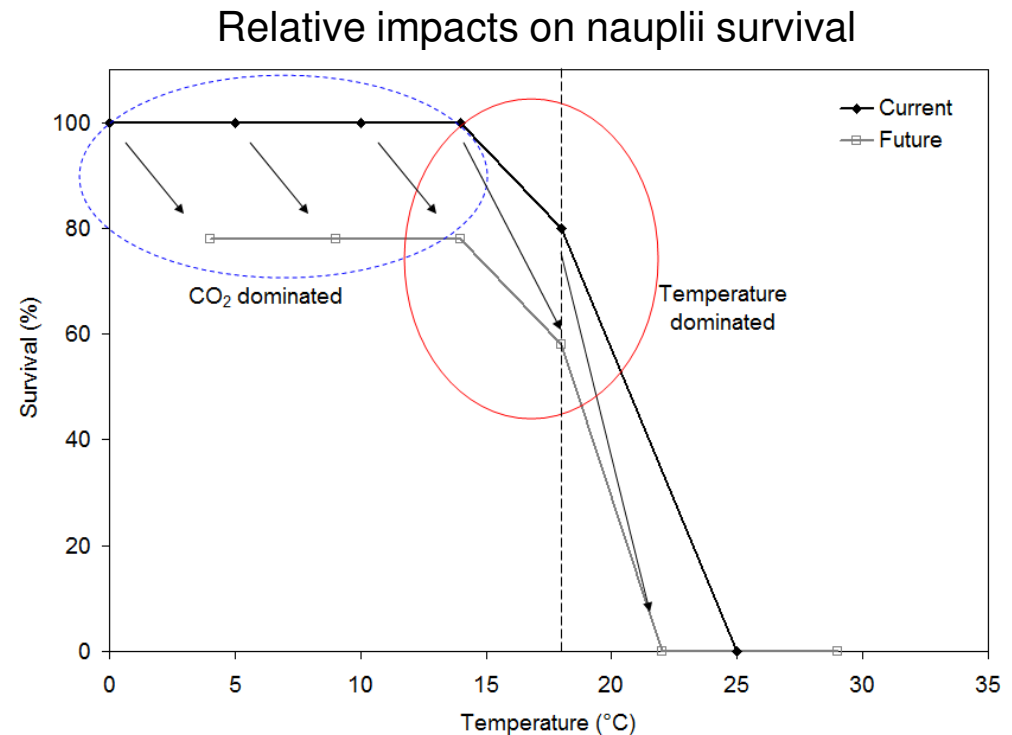
Do populations from **lower latitudes** provide the answers? Or are they just **confusing** the situation?

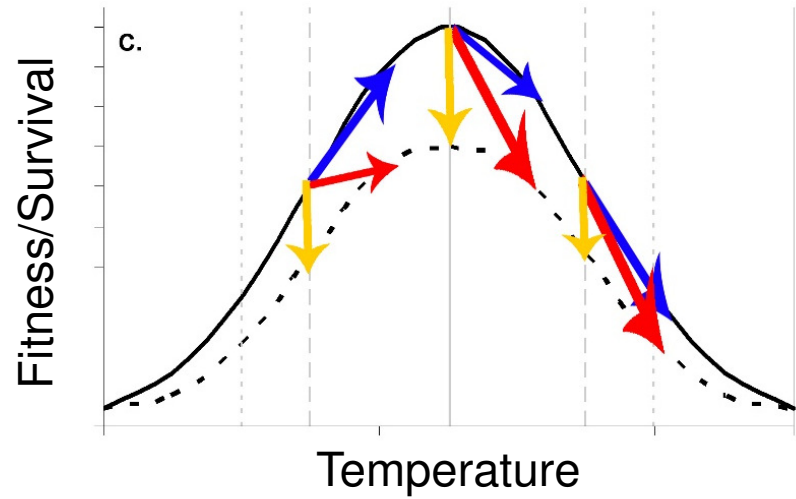





- Many biological processes occur at rates set by temperature
- Rates therefore vary in populations of same species across geographical range
- Results in different morphologies of individuals
- ***How are these local differences mediated by additional stress e.g. OA?***

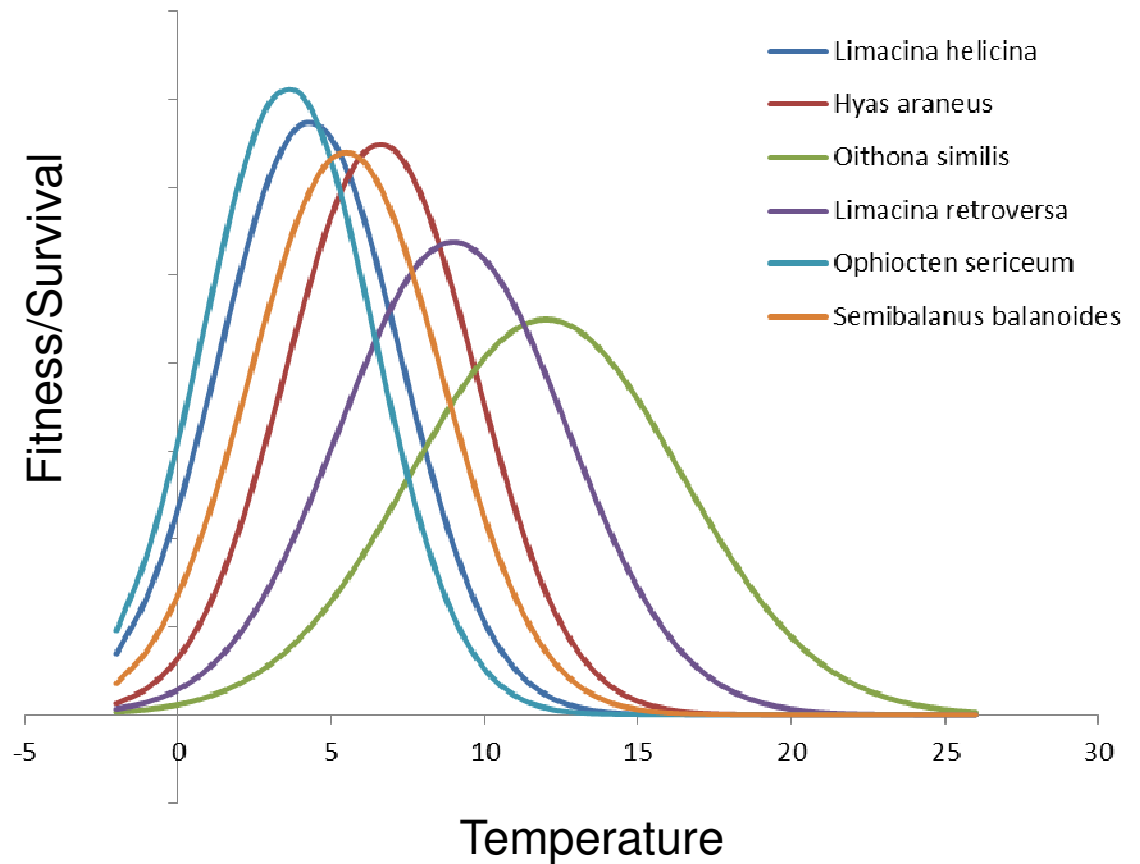


- Nauplii survival known to be **temperature** dependent
- In experiments, **high CO₂ lowers survival** at all temperatures
- But depending on position in range, a smaller shift in temperature may be more important than an increase in CO₂...
- **Non-linear responses** across a species range





-  Ocean Acidification response only (-ve)
-  Temperature & acidification response (+ve & -ve)
-  Temperature response only (+ve & -ve)



- **Integrate** biology (especially ecology), chemistry, physical observations & studies.
- Priority **locations**: Canadian archipelago, shelf regions, under-ice systems
- Assess **current variability** – what are organisms able to cope with now; what do they currently experience (e.g. copepods); what will they experience – is it what we expect (e.g. corals: OA vs T).
- **Benthic communities** especially on the shelves; areas of upwelling; areas of large freshwater input.
- **Multiple stressors**, especially warming and OA (“heat map”).
- Invasive or **northward moving** species.

Thank you & any questions?

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