Ocean Acidification

Another threat from increasing Carbon Dioxide (CO_2) in the atmosphere

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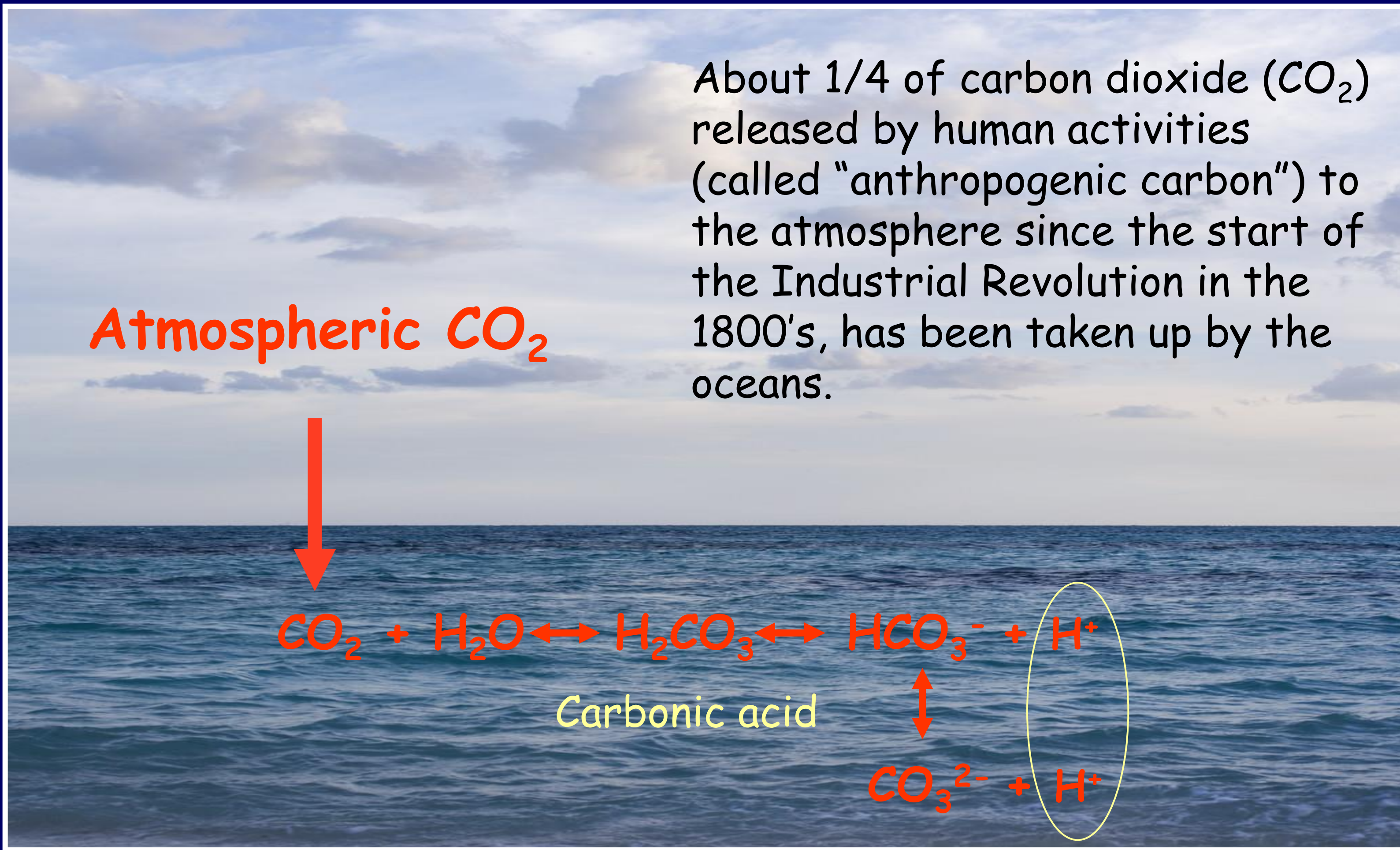
What is Ocean Acidification?



pH is a measure of acidity

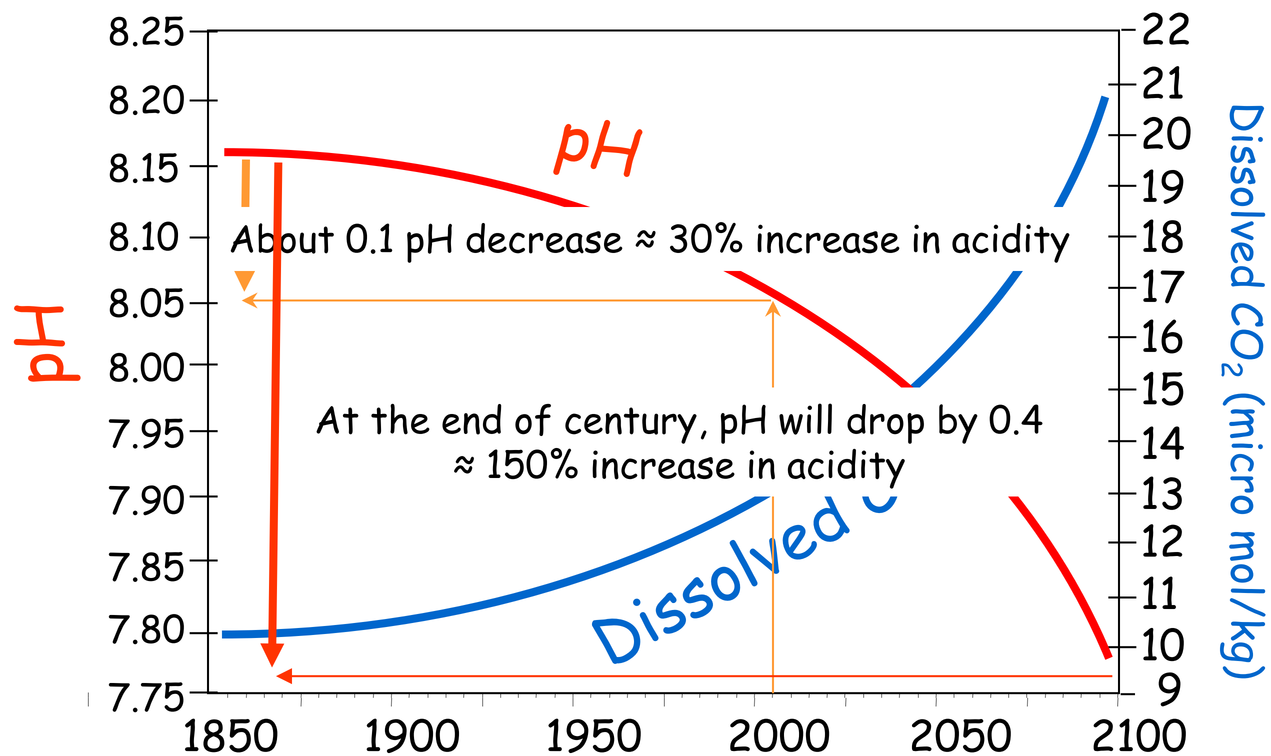
$$pH = -\log_{10}[H^+]$$

	pH	
strong base	14	Household lye
	13	Oven cleaner
	12	Household bleach
	11	Household ammonia
	10	Hand soap
	9	Baking soda
		Sea Water (8.16, pre-industrial)
	8	
neutral	7	Blood
	6	Milk
	5	Coffee
	4	Wine
	3	Vinegar, Carbonated beverages, Beer
	2	Lemon juice
	1	Gastric acid
strong acid	0	Battery acid

Decreasing pH
Increasing acidify

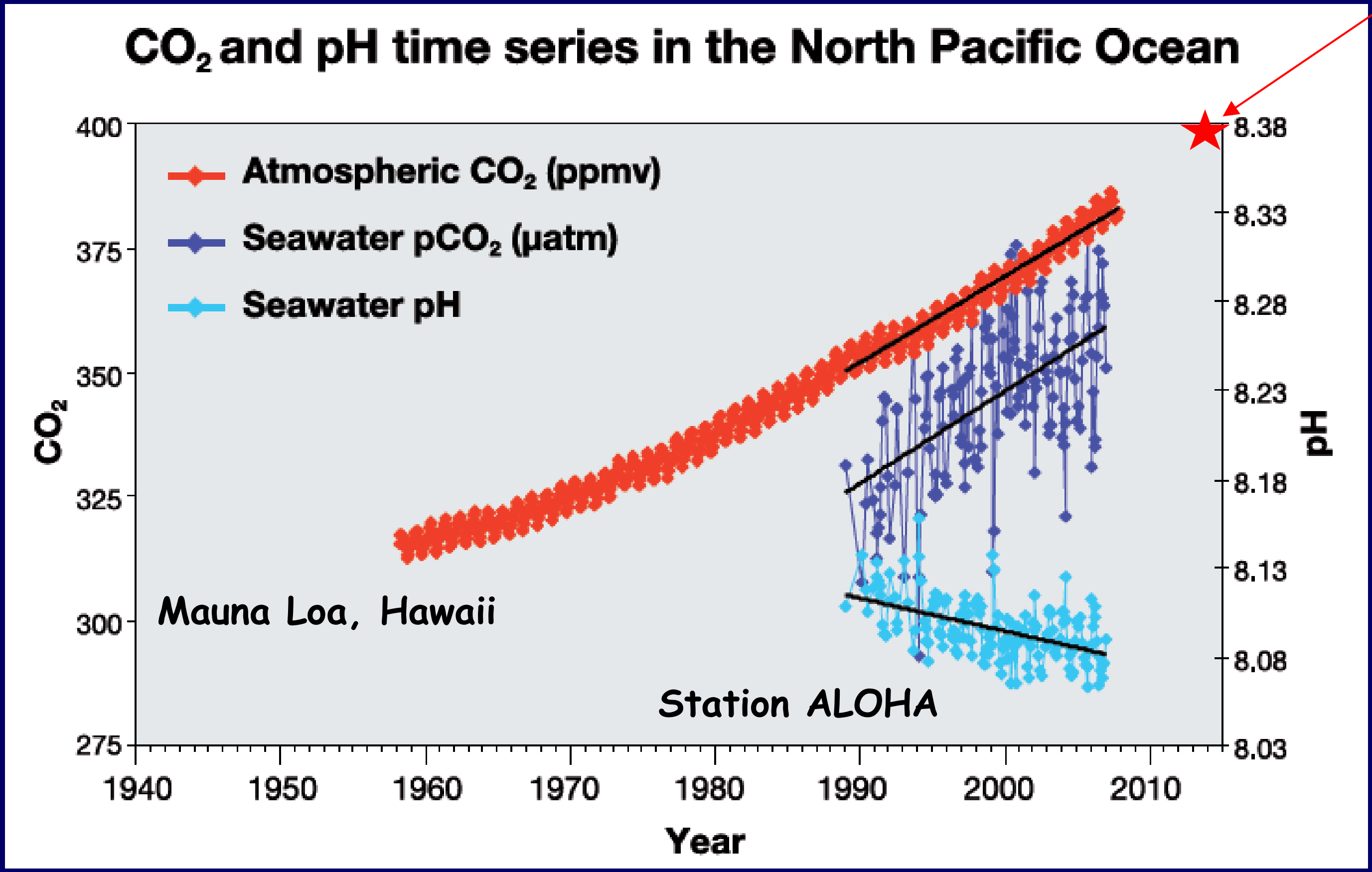
Ocean Acidification

Historical and Projected pH and Dissolved CO_2 in the Ocean



Feely et al., 2006

398.53ppm January 18, 2014

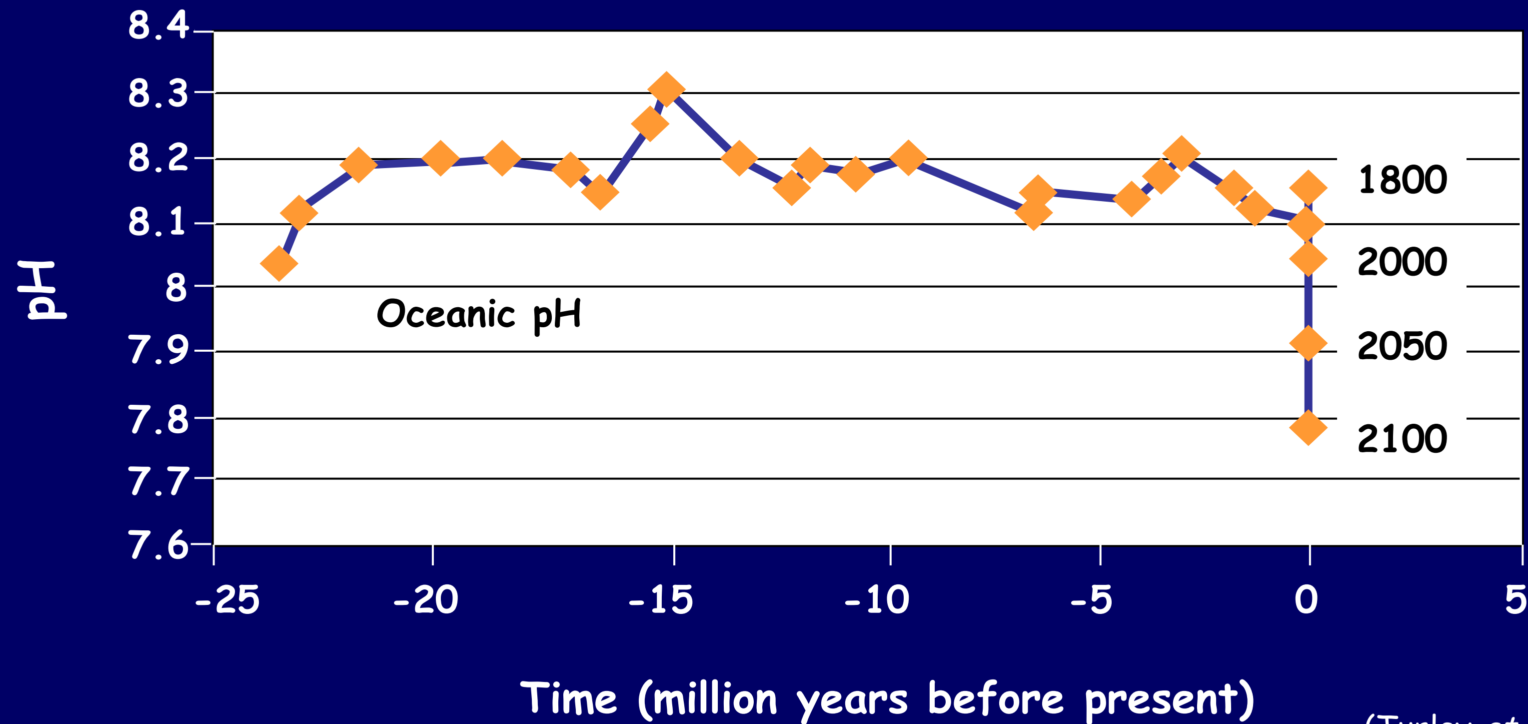


May 10, 2013, daily averages temporarily reached 400 ppm

Figure credit: Richard A. Feely, Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration, USA, with atmospheric data from Pieter Tans and seawater data from David Karl. Adapted from Feely (2008) in Levinson and Lawrimore (eds), *Bull. Am. Meteorol. Soc*, 89(7): S58.

From "A summary for Policymakers from the Second Symposium on the Ocean in a High-CO_2 World"

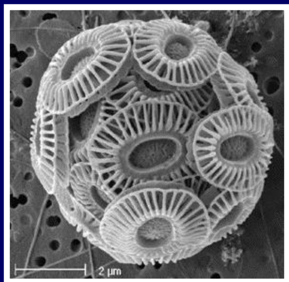
Past and Contemporary pH



(Turley *et al*, 2006)

Can organisms adapt to this rate of change ?
How do ecosystems respond to this change?

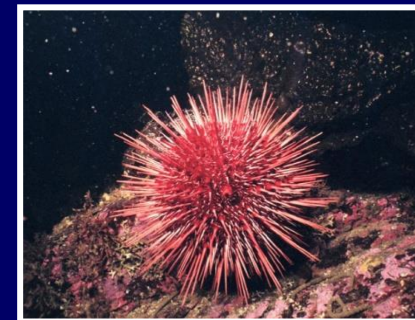
Many life processes are sensitive to carbon dioxide and pH; The most direct impact would be to organisms that form calcium carbonate ($CaCO_3$) shells and skeletons because acidity increases the solubility of $CaCO_3$



Phytoplankton
Coccolithophore

Zooplankton
Pteropod
(sea butterfly)

Zooplankton
Foraminifera



Echinoderm
Sea urchin

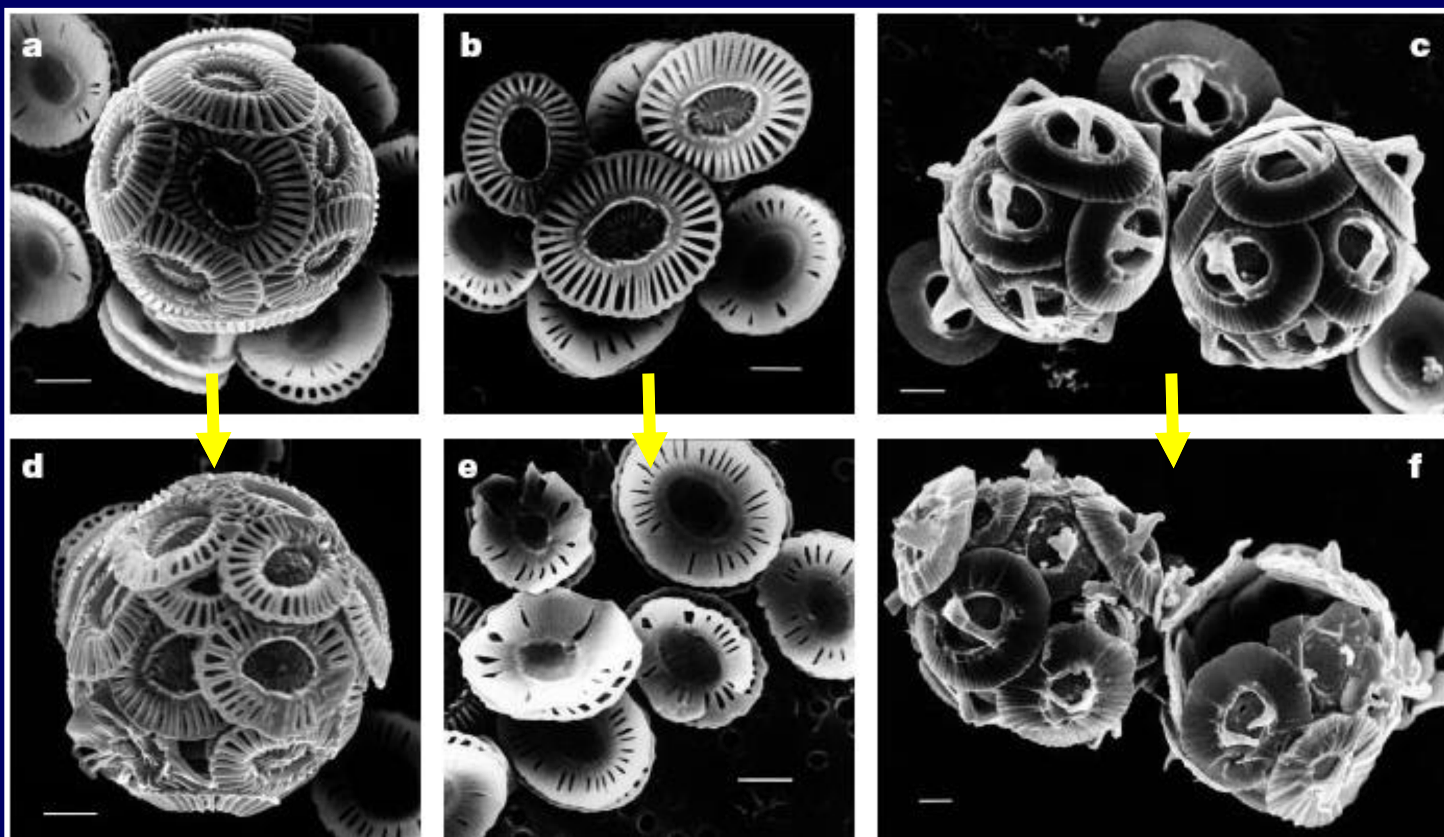
Crustacean
Lobster

Echinoderm
Brittle star

Deep-sea coral

Mollusc
Scallop
Oyster
mussel

Coccolithophore, *Emiliania huxleyi*, was exposed to high pCO_2 = low pH water



pCO_2=300 ppm (~pre-industrial level)
pH~8.1

pCO_2=780~850 ppm (2~3 times of pre-industrial level)
pH~7.8

Decrease in formation and malformation of shell

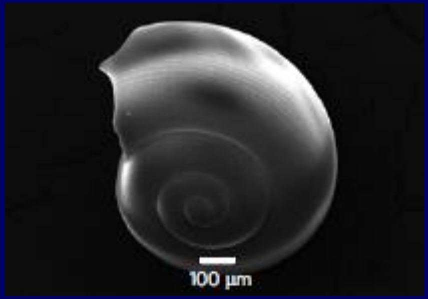
Riebesell et al., 2000

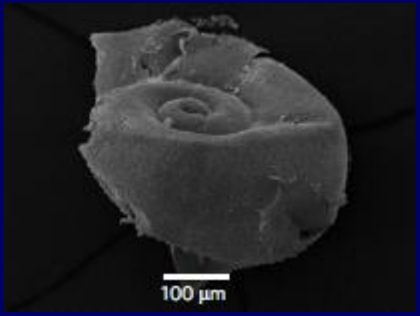
Pteropod (sea butterfly) is an important food source in northern waters for fish such as herring, salmon and cod

placed pteropods in seawater at the pH projected for the Southern Ocean by 2100.

Fabry, 2012

Within 48 hours, the pteropod shell began to dissolve

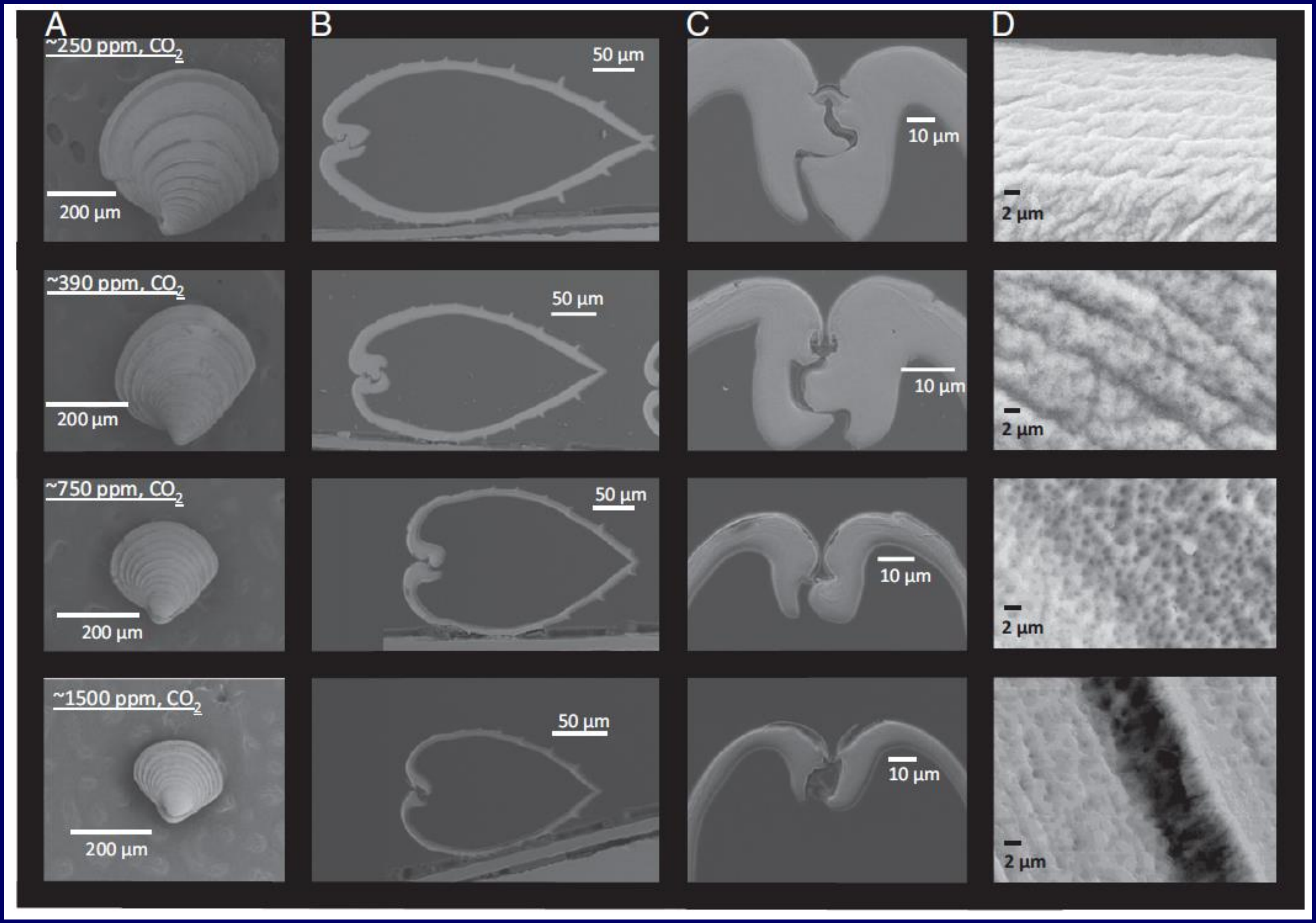




Extensive dissolution of live pteropods in the Southern Ocean, Bednaršek et al., 2012

SEM images of M. mercenaria (quahog or hard clam) larvae (baby) grown under a range of CO_2 concentrations (36-day old)

Lower pCO2
higher pH



higher pCO2
lower pH

(Talmage and Gobler, 2010)

In recent years, natural and hatchery larval production have been severely depressed in the Pacific Northwest, and a lack of sufficient "seed" has threatened an industry with a total economic value estimated US$278 million as of 2009 (Pacific Coast Growers Association, 2010)

Ocean Acidification Linked with Larval Oyster Failure in Hatcheries (NSF, press release April, 12, 2012) - Increase in ocean acidification led to collapse of oyster seed production at Oregon hatchery

Ocean Acidification Can Mess with a Fish's Mind ?

In more acidic waters clown fish wander too far from safety, sea snails fail to avoid prey

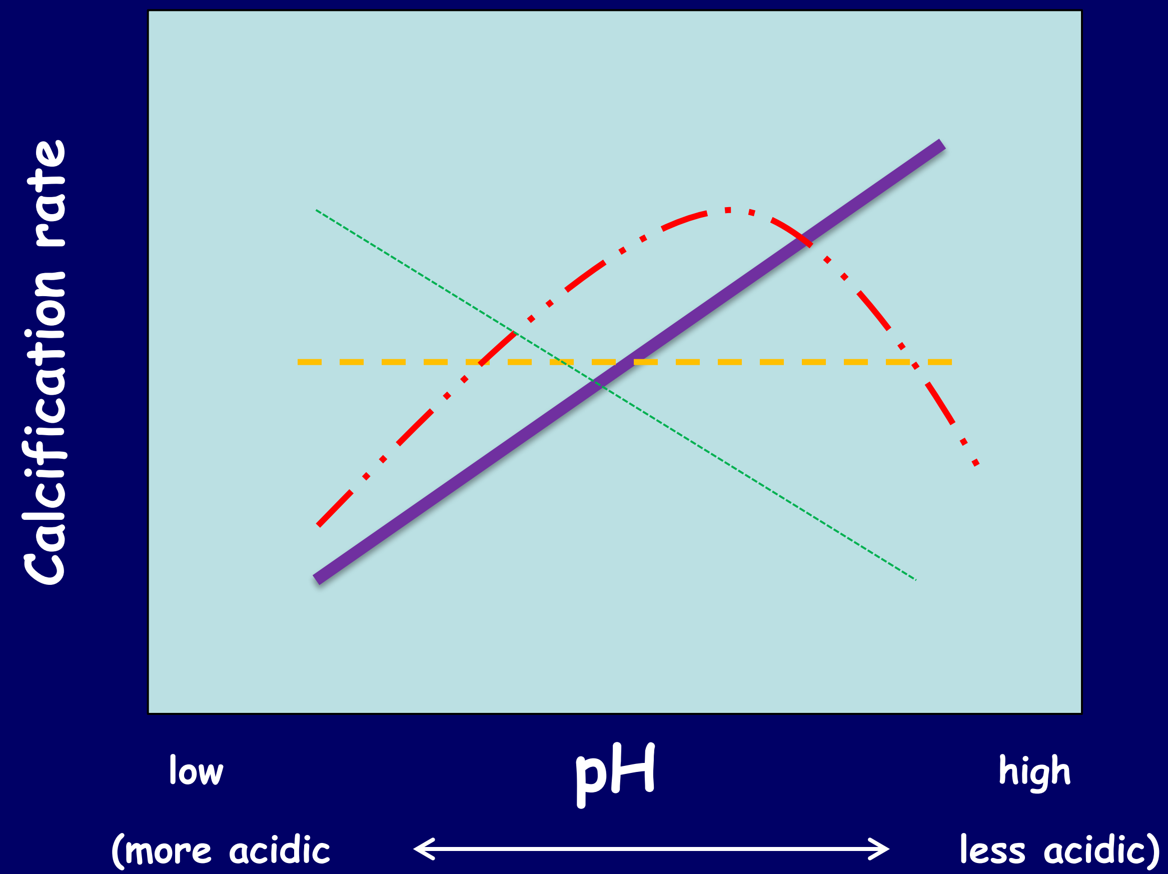
A reef fish was exposed to high CO_2, which interfered with their sense of smell.

ocean acidification could cause sensory and behavioral problems for many sea creatures if global CO_2 levels continue to rise

Yes, Nemo

(Fischetti, 2012, Scientific American)

More you study, you realized how complex biological responses to ocean acidification are….



Winners and Losers

Different response of calcifiers to elevated CO_2 conditions may result in competitive advantages that could drive the re-organization of many ecosystems, which in turn, could have significant ecological and biogeochemical implications.

Studies for Ecosystem Responses

Naturally high CO_2 environment (under-sea volcanoes)

Long-term ecosystem response
- Shift in the benthic community composition (pH 7.4 – 8.2)
- No indication of adaptation
- Winners (sea grasses, brown algae) and losers (calcareous group)

Hall-Spencer et al., 2008

Increasing CO_2 in the Atmosphere

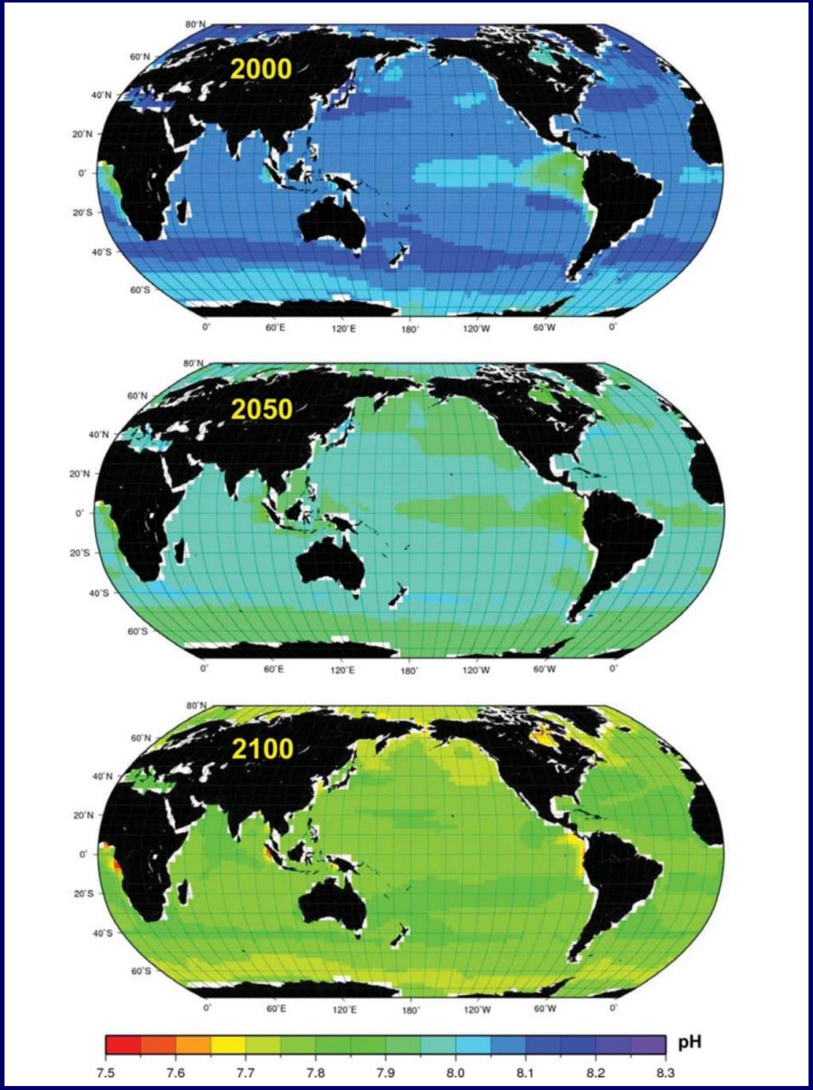
Ocean Acidification

(chemical environment change in the ocean)

Physiological Change

Ecosystem Change

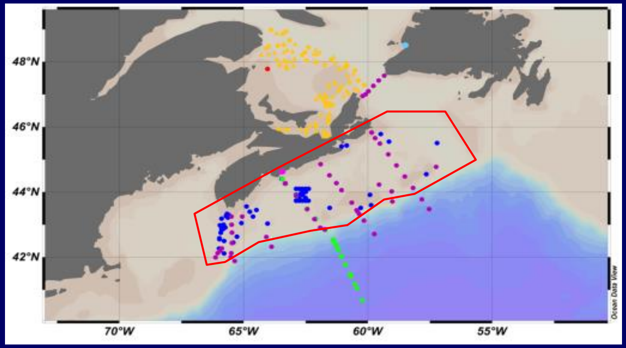
Model projections of global patterns in decreasing surface pH for historical fossil fuel emissions to 2000 and SRES A2 emissions From the Canadian Earth System Model CanESM-1.0 (Christian et al., 2010).



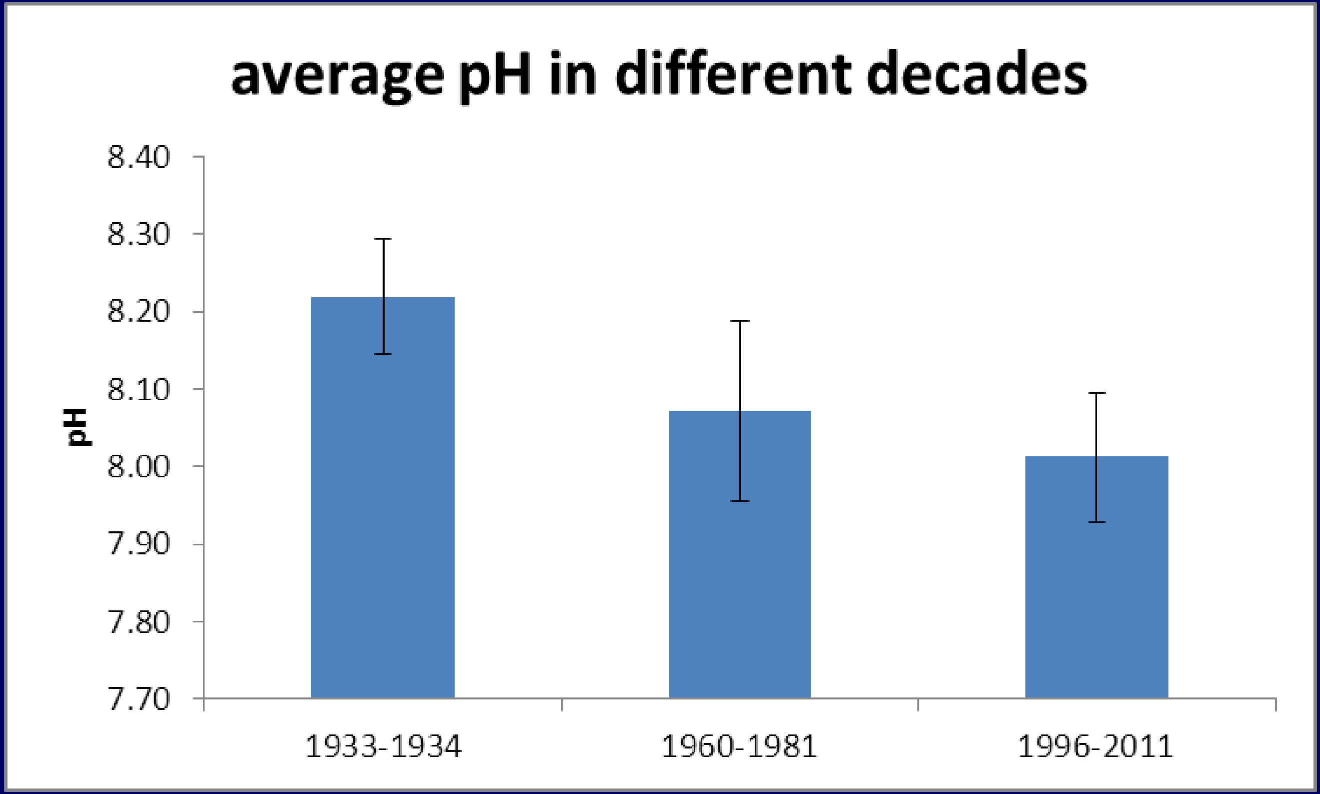
Denman et al., 2011

- **Cold water takes up more CO_2 from the atmosphere**
- **$CaCO_3$ (shells and skeletons) more soluble in cold water**

High-latitude surface waters are predicted to experience detrimental effects earliest, likely within decades



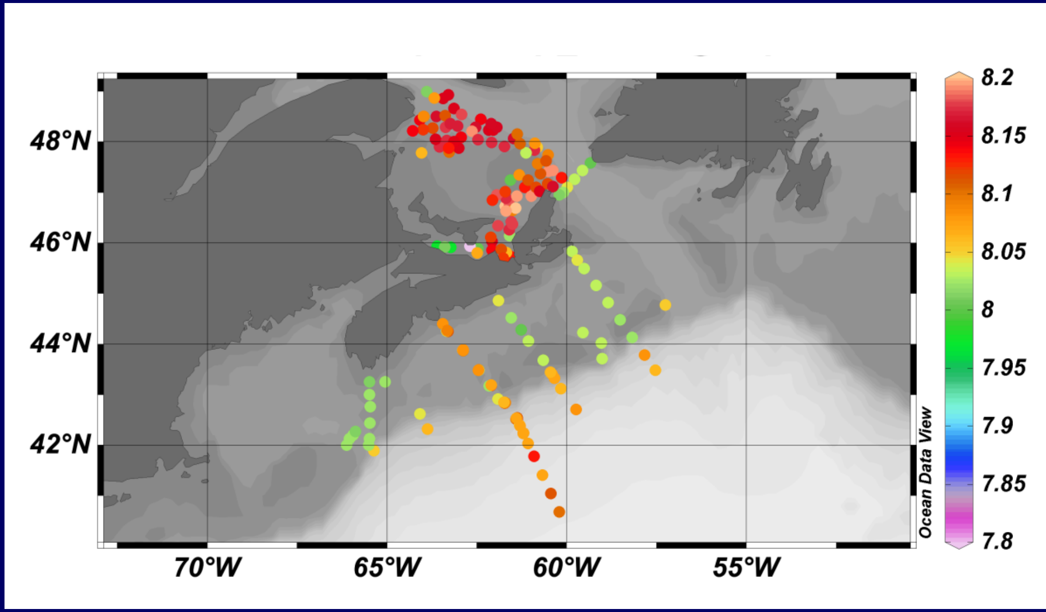
pH change on the Scotian Shelf



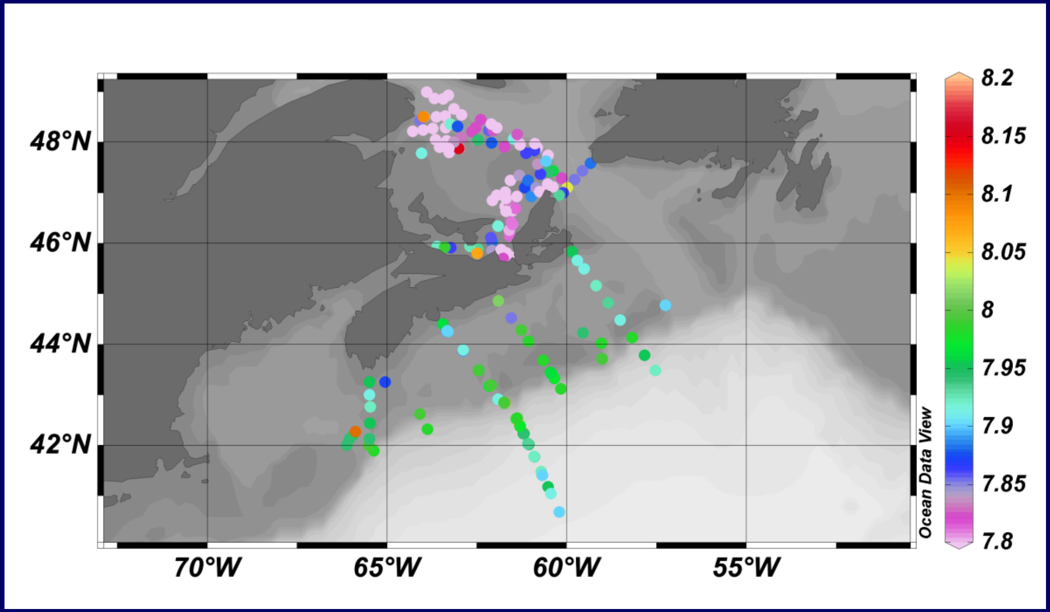
Decrease rate 0.003/year, global average=0.002/yr, Iceland shelf = 0.0024/yr

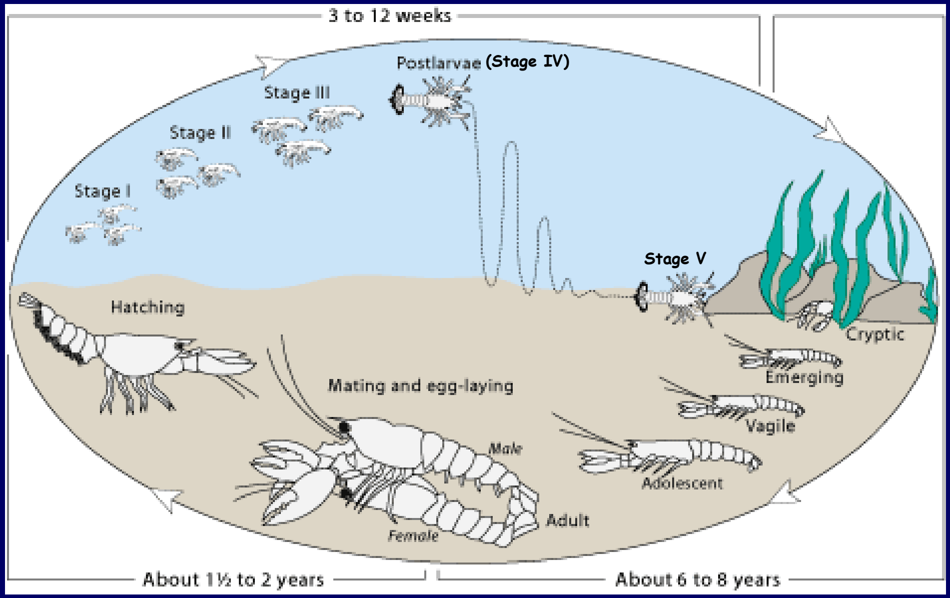
pH(total) distribution at surface and bottom water (data collected after 2006)

Surface (<10m)

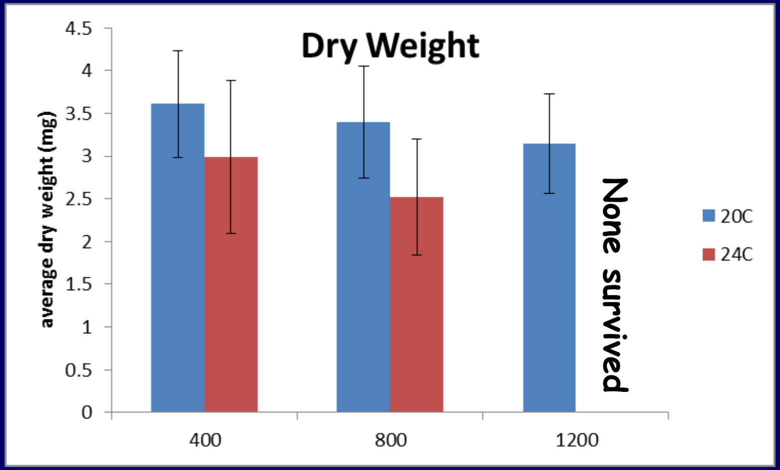


bottom

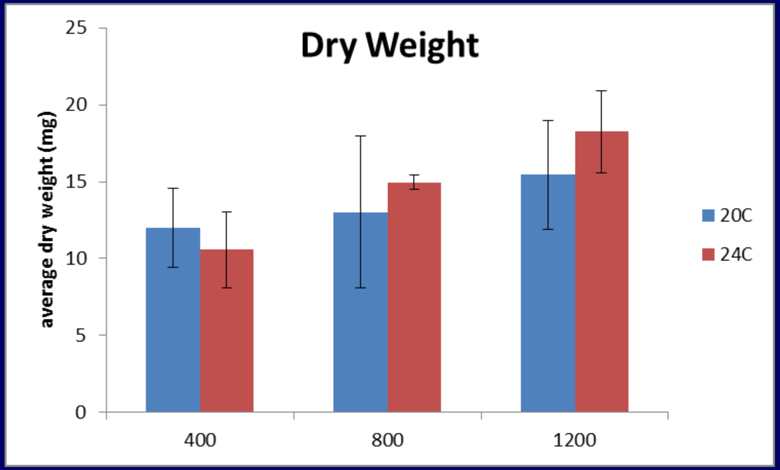




stage IV



stage V



Socio-Economic Impact

- Total value of commercial sea fishery landings in Atlantic Canada is $1.83 billion in 2012
- over 85% of it is from shellfish
- Among shellfish, $664 million was from the lobsters, $435 million from crabs and $334 from shrimp
- Aquaculture production of bivalves (Clams/Quahaug, Oyster, Scallop and Mussel) produces over $158 million in the Atlantic Canada
- post-catch processing and shipping etc. contribute more to Nova Scotia's Gross Domestic Product and support regional household incomes
- Ocean acidification, therefore, imposes the real and urgent threat to the Atlantic Canada's livelihood.

Human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future (Revelle and Suess, 1957)

Ocean Acidification is:

- underway
- already detectable
- accelerating (but recovery will be slow)
- severe damages are imminent
- will have socioeconomic impacts
- can be controlled only by limiting future atmospheric CO_2 levels

(Monaco Declaration, 2009)

Thank you