Sentinel studies of ocean acidification in the Arctic Ocean and Japanese coasts

MARINE ECOLOGY RESEARCH INSTITUTE

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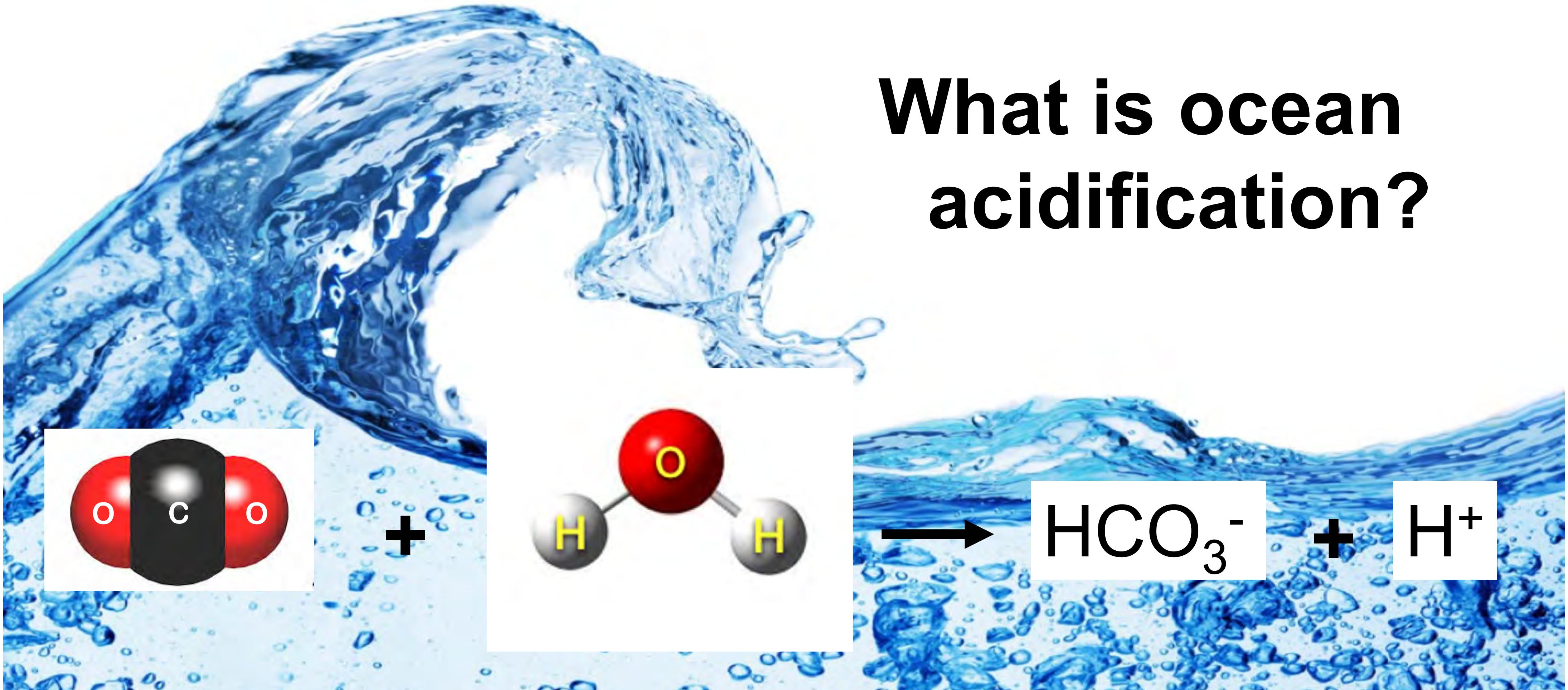
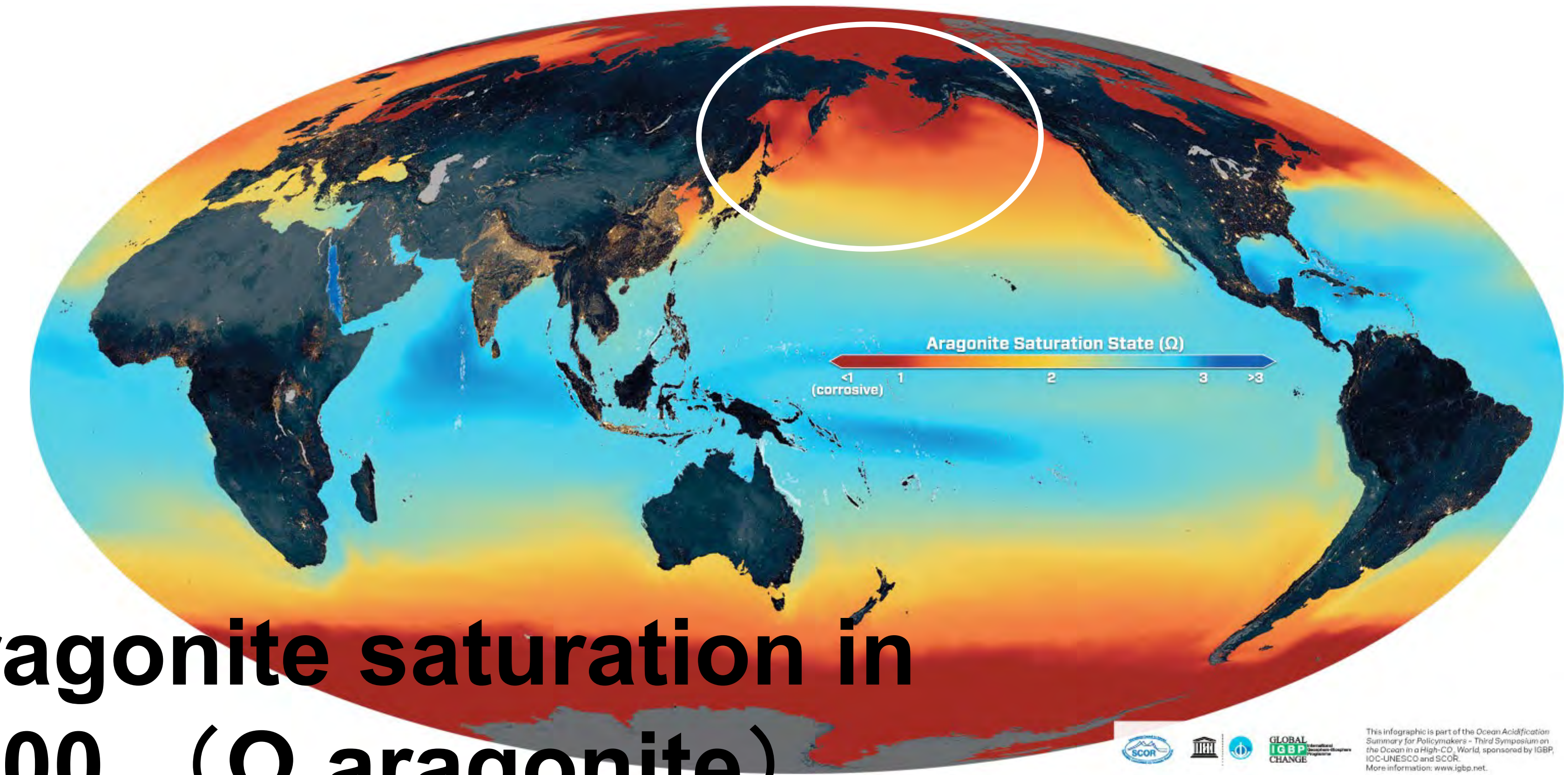
What is ocean acidification?



H^+ is described as “pH” which is defined as the decimal logarithm of the reciprocal of the hydrogen ion activity a_{H^+} in a solution.



Aragonite saturation in 2100　(Ω aragonite)

Sub-Arctic and Polar Seas: Low CO_3^{2-} brings low Ω

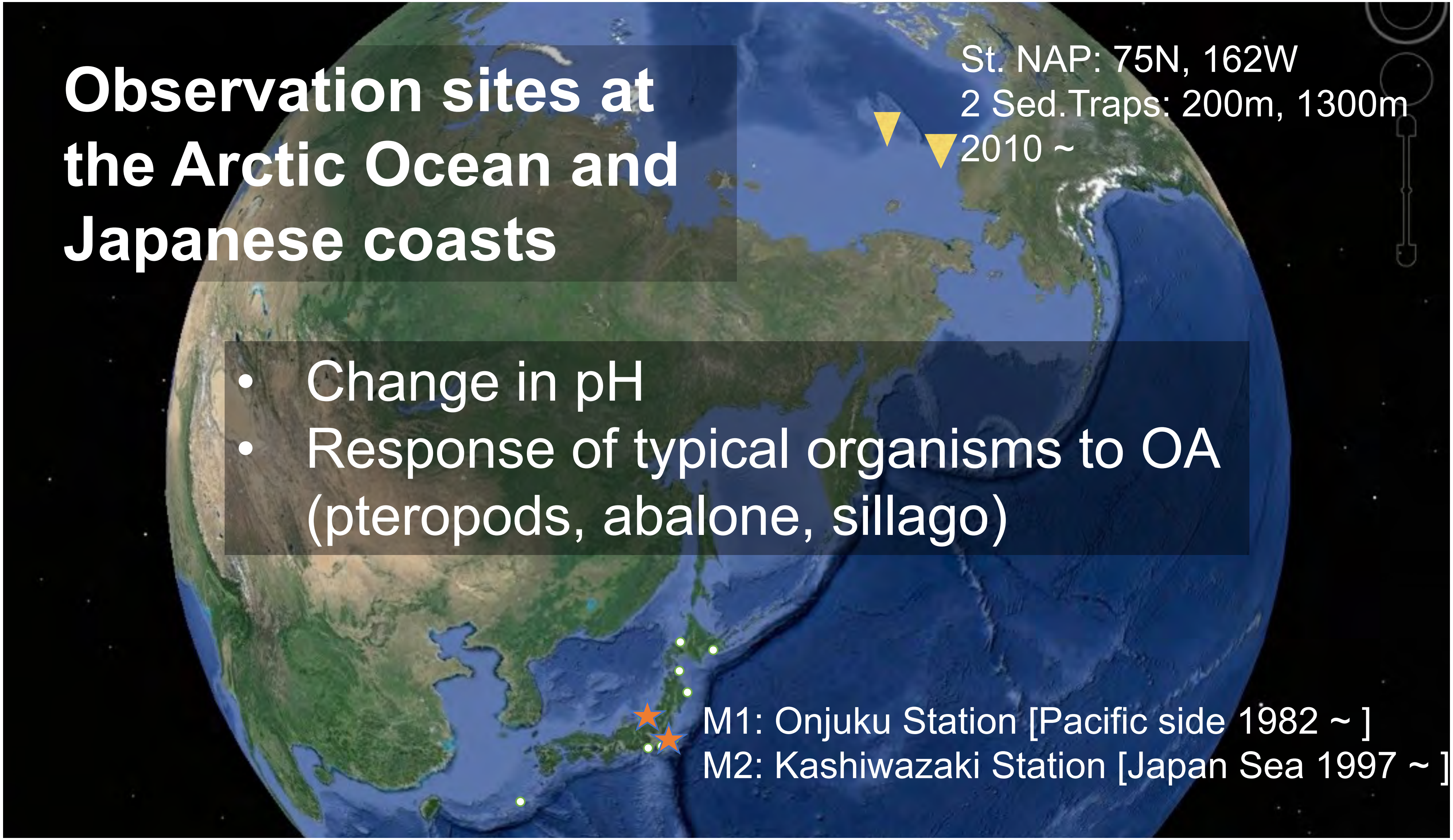
$$\Omega = [Ca^{2+}]\,[CO_3^{2-}] \,/\, K'_{sp}$$

Saturation index　(Ω)

K'_{sp} : solubility product of calcite/aragonite

Ω>1: precipitation(shell preserved)

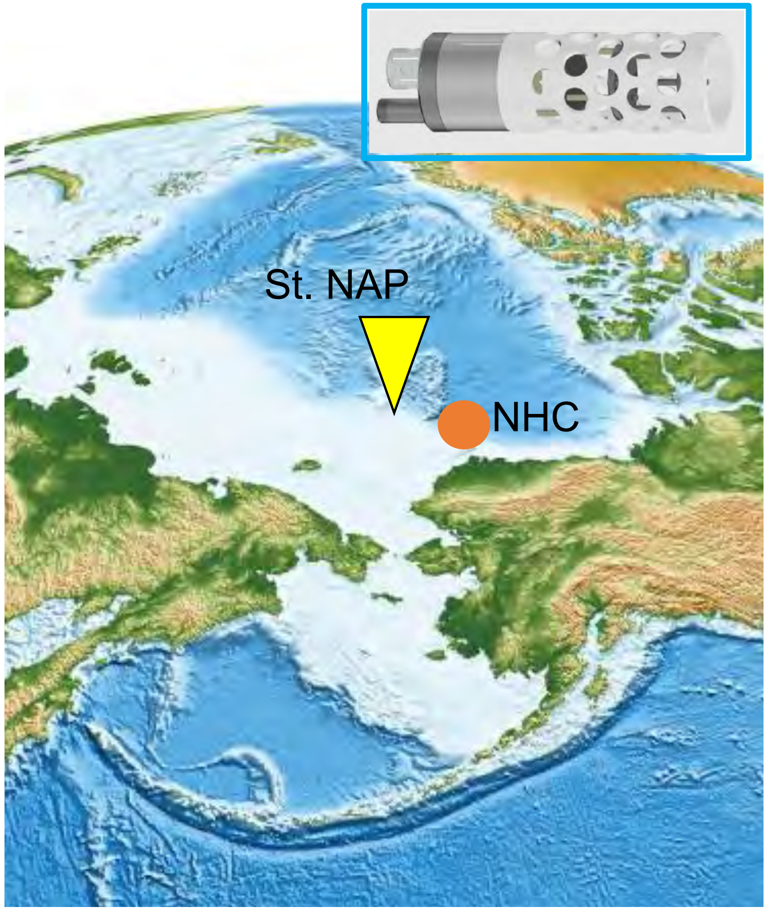
Ω<1: undersaturation (shell dissolved)

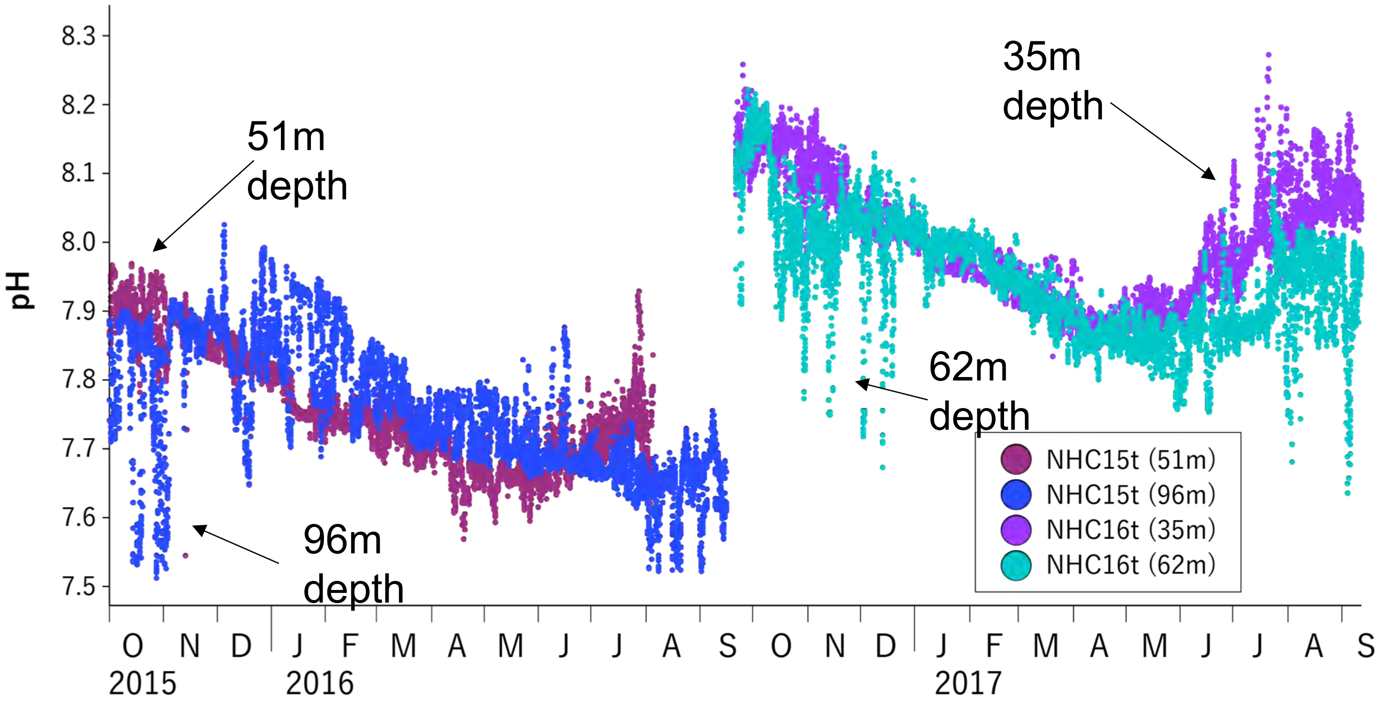


Observation sites at the Arctic Ocean and Japanese coasts
St. NAP: 75N, 162W
2 Sed.Traps: 200m, 1300m
2010 ~
• Change in pH
• Response of typical organisms to OA (pteropods, abalone, sillago)
M1: Onjuku Station [Pacific side 1982 ~]
M2: Kashiwazaki Station [Japan Sea 1997 ~]

Seasonal change in subsurface pH of the western Arctic Ocean measured by glass electrode sensor (Kimoto Co. LTD)

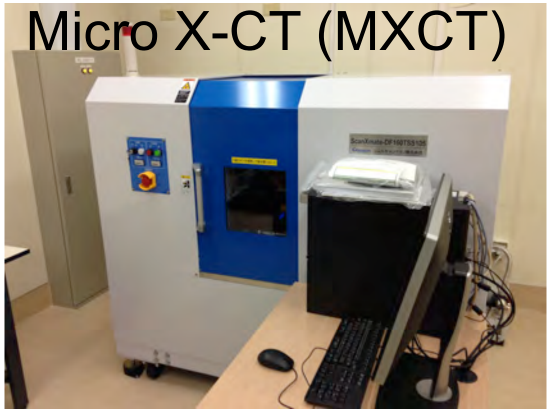
Measurement timing is once a 60min. Resolution is 0.001pH and response speed is within 20 sec. Repeat accuracy is within ± 0.01pH (The 3rd winner of Accuracy Prize, XPRIZE competition). All data is calibrated after observation.

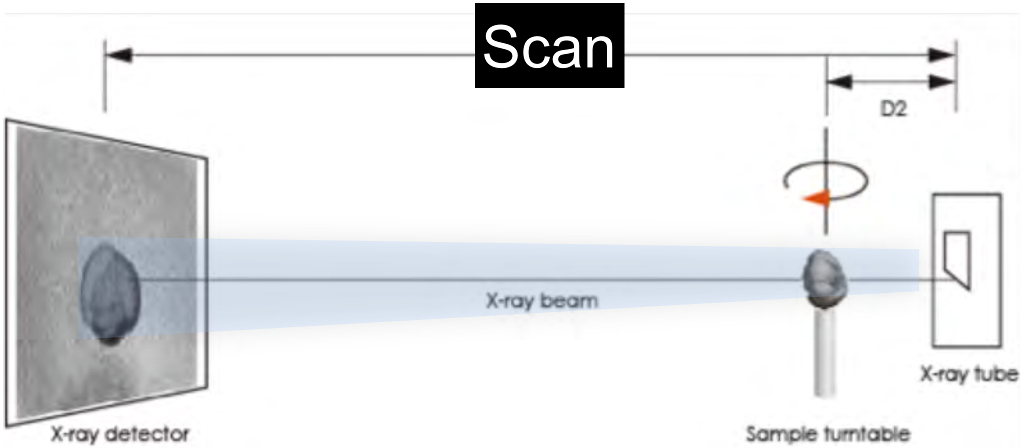


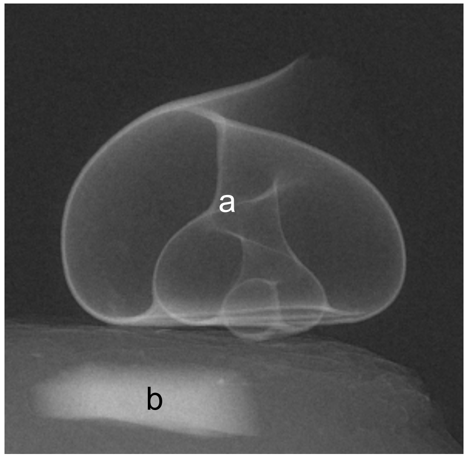


- Remnant and newly ventilated Pacific Winter waters (having relatively low but different pH values) are intricately laminated between 50-150m water depth.
- Common trend1: Relatively low winter and relatively high summer
- Common trend2: Minimum pH values during summer and the beginning of sea-ice season

Measurement of pteropods carbonate density by micro focus X-ray Computing Tomography method



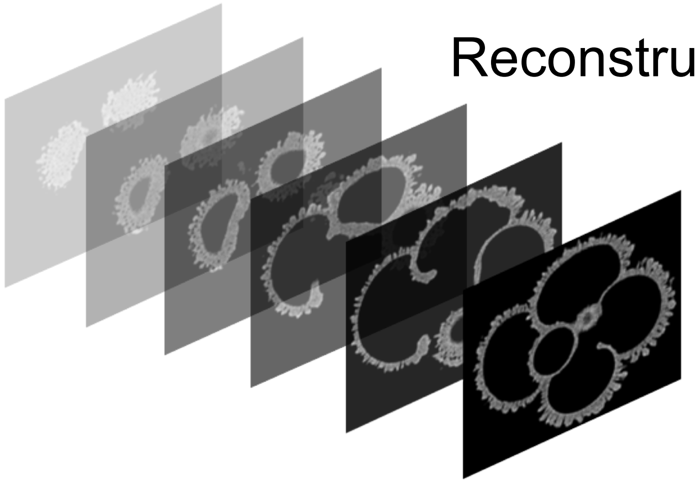




a. Specimen

b. Standard material (Calcite)

Reconstruct



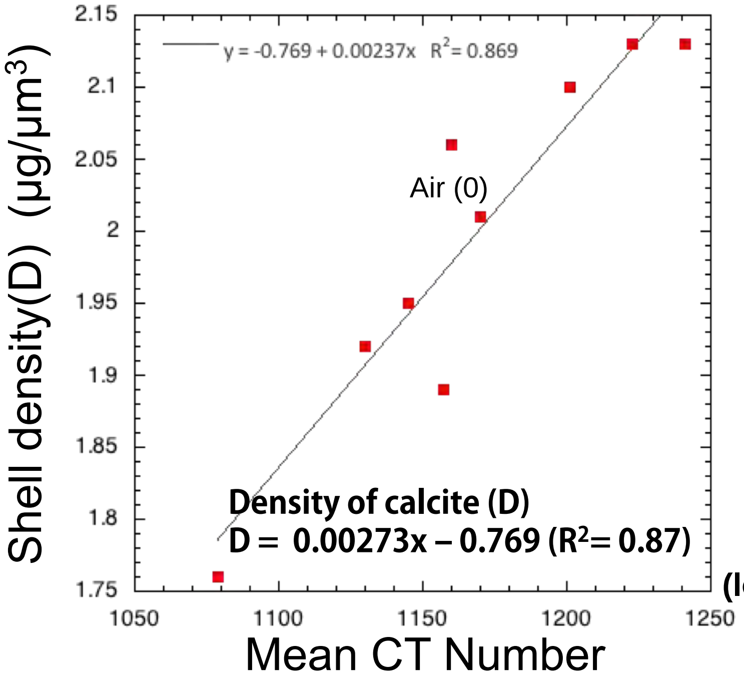
Calcite CT Number as a shell density index

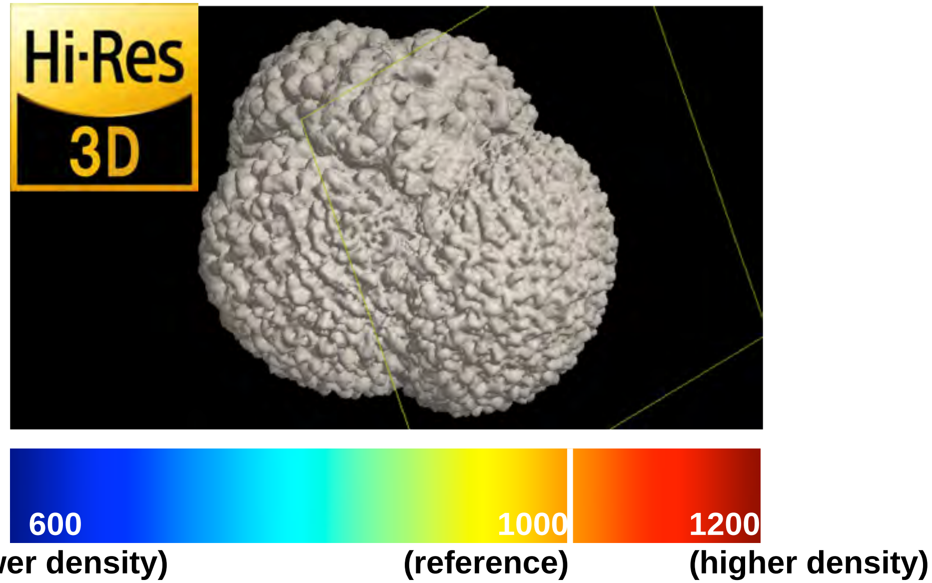
relative value of X-ray attenuation coefficient in each voxels

$$\text{Calcite CT Number} = \frac{\mu_{sample} - \mu_{air}}{\mu_{calcite} - \mu_{air}} \times 1000$$

µsample: X-ray attenuation coefficient of samples
µair: X-ray attenuation coefficient of the surrounding air = -1000
µcalcite: X-ray attenuation coefficient of calcite (standard material: Calcite or Aragonite) = 1000

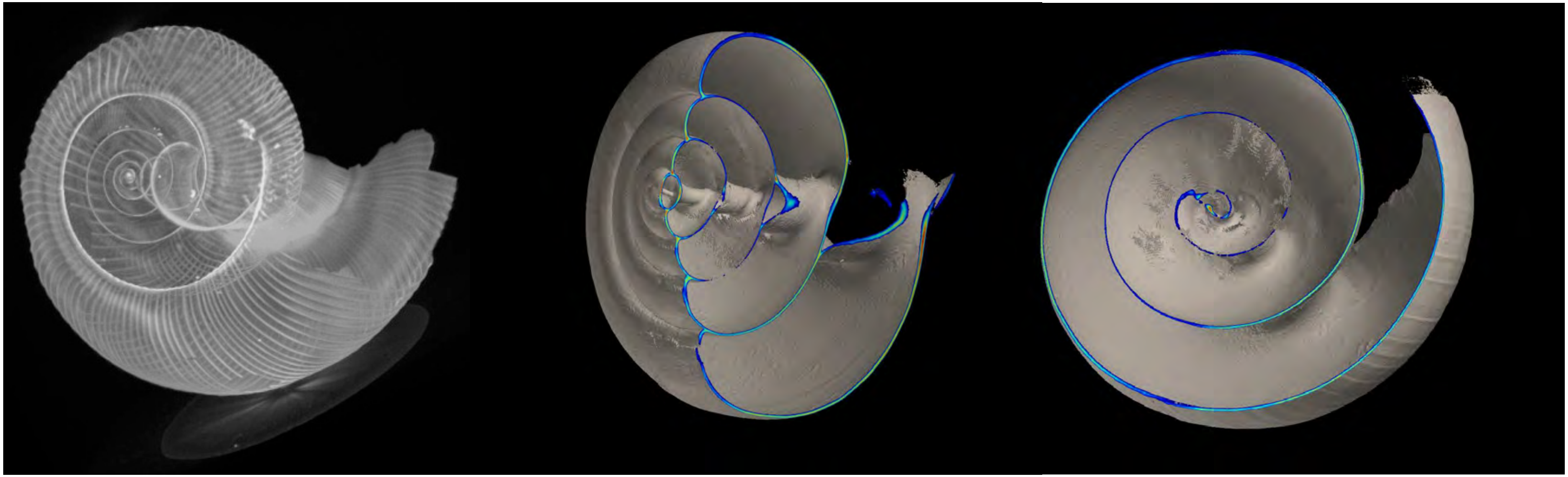
Mean CT number vs Shell density





Kimoto et al., in prep

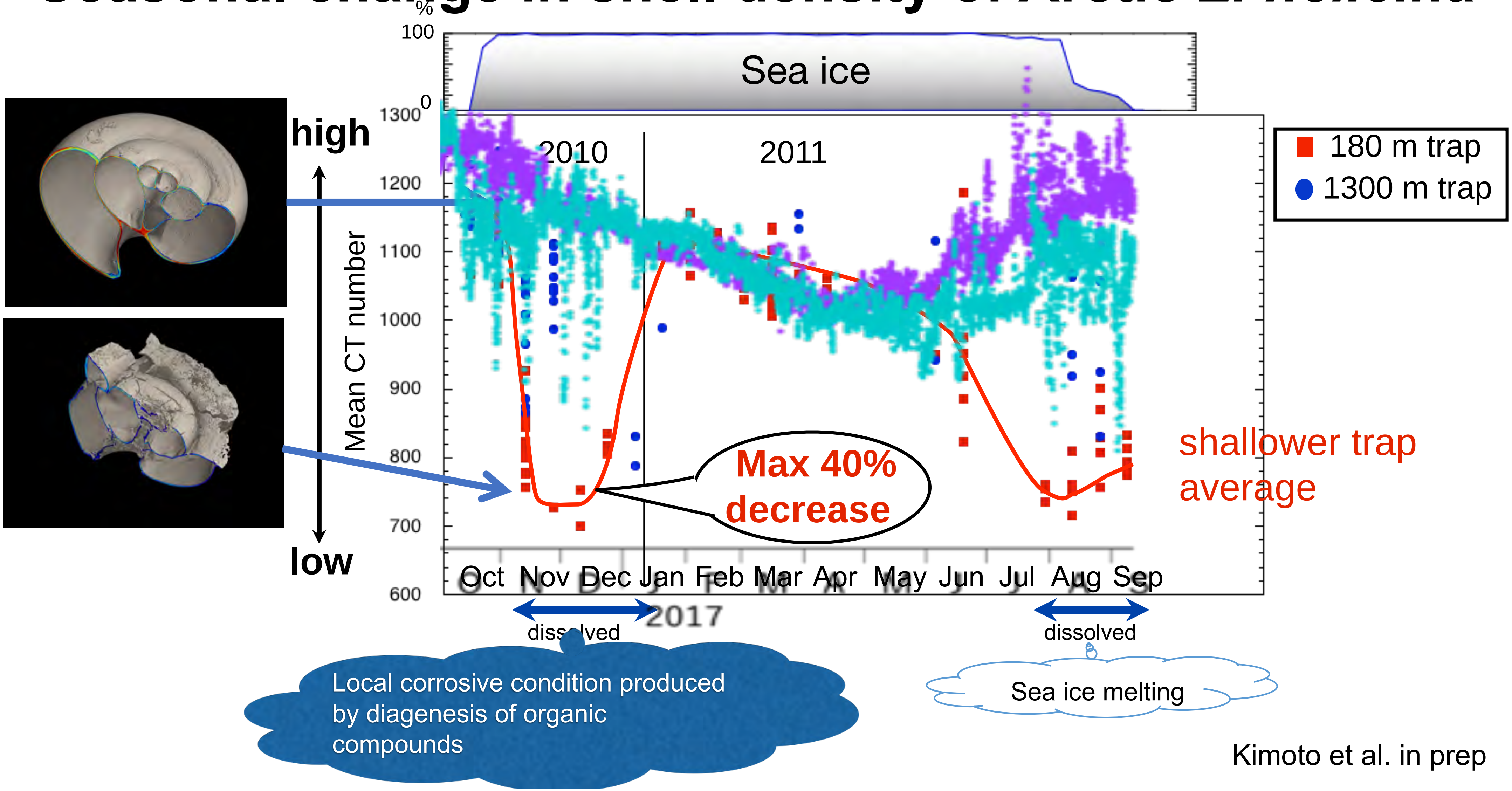
Precise shell density analysis of Sea butterfly (*Limacina helicina*, Thecosomatous pteropod)



Transparent image
(spatial resolution: 0.5 um)

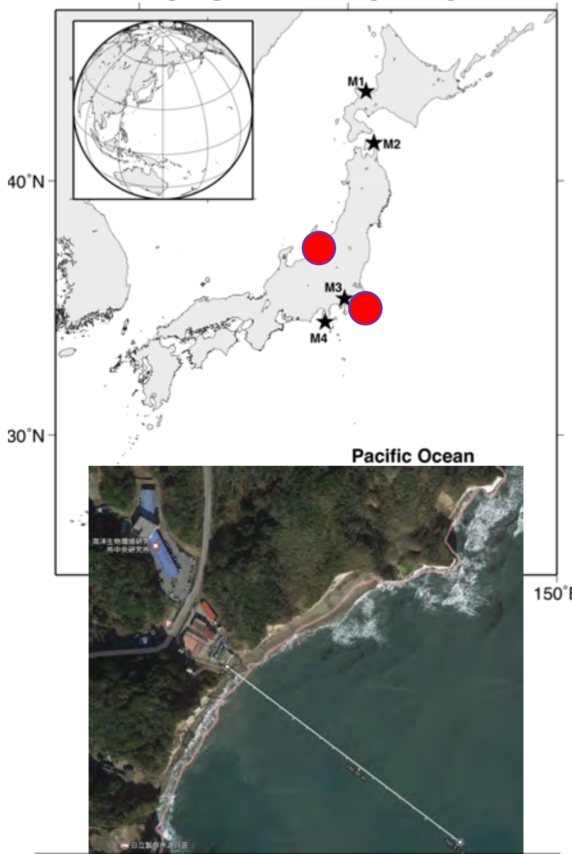
Distribution of Shell density
(Unit: ug/um^3)

Seasonal change in shell density of Arctic *L. helicina*

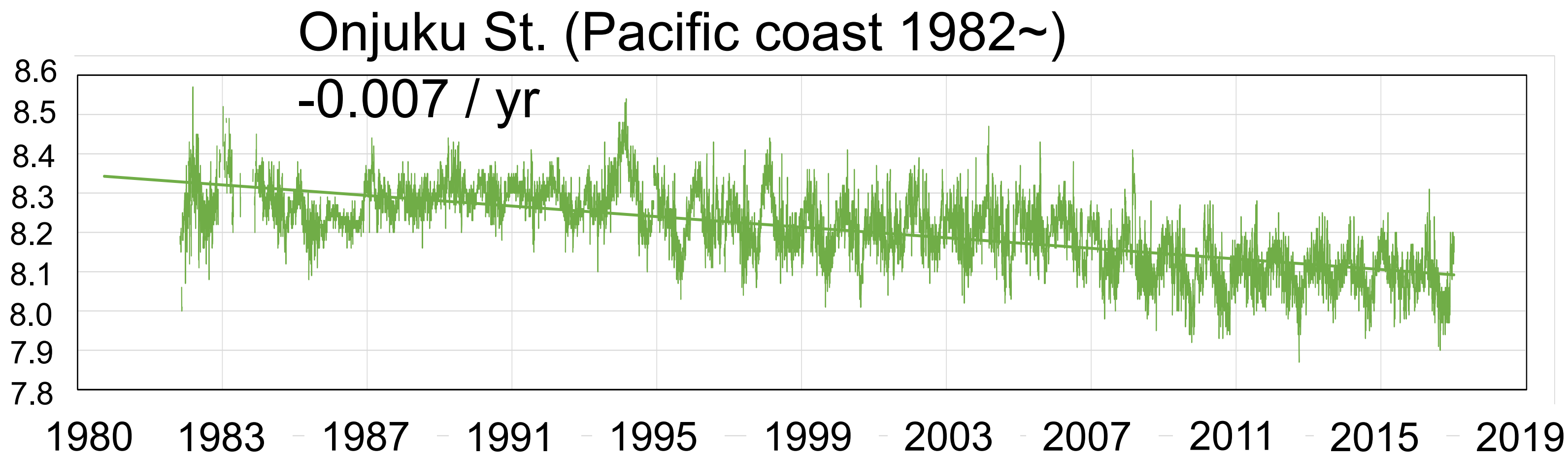


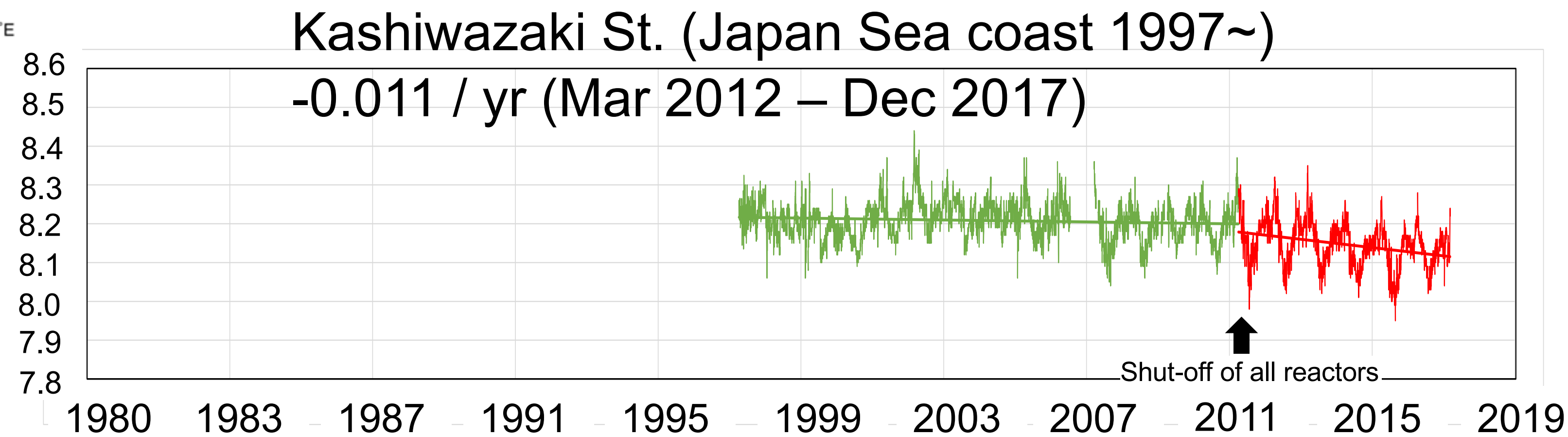
Kimoto et al. in prep

Changes in pH at Onjuku St, Pacific side and Kashiwazaki St, Japan Sea side



Seawater inlet (350m offshore, 11m depth)
Intake quantity (75 m^3/hour)

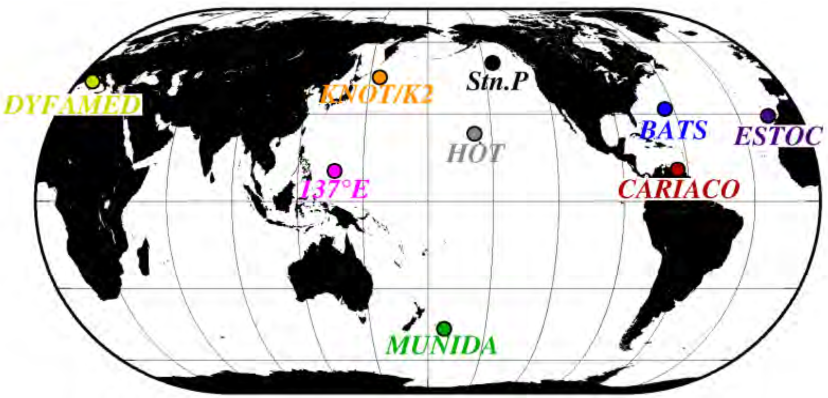




Annual change in pH

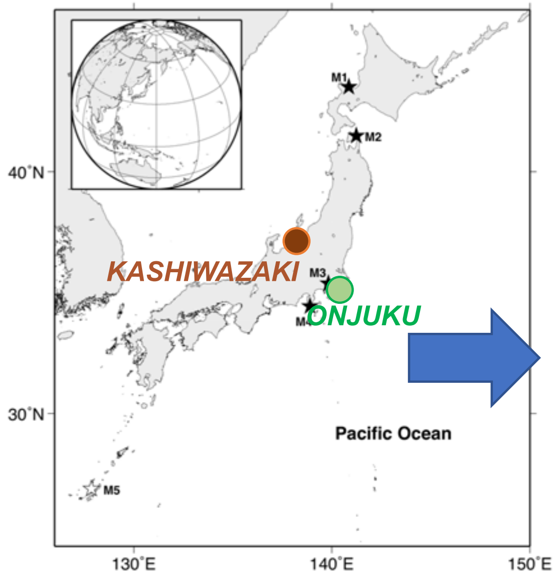
Comparison between pelagic and Japanese coastal zones

WMO GHG Bulletin 2014



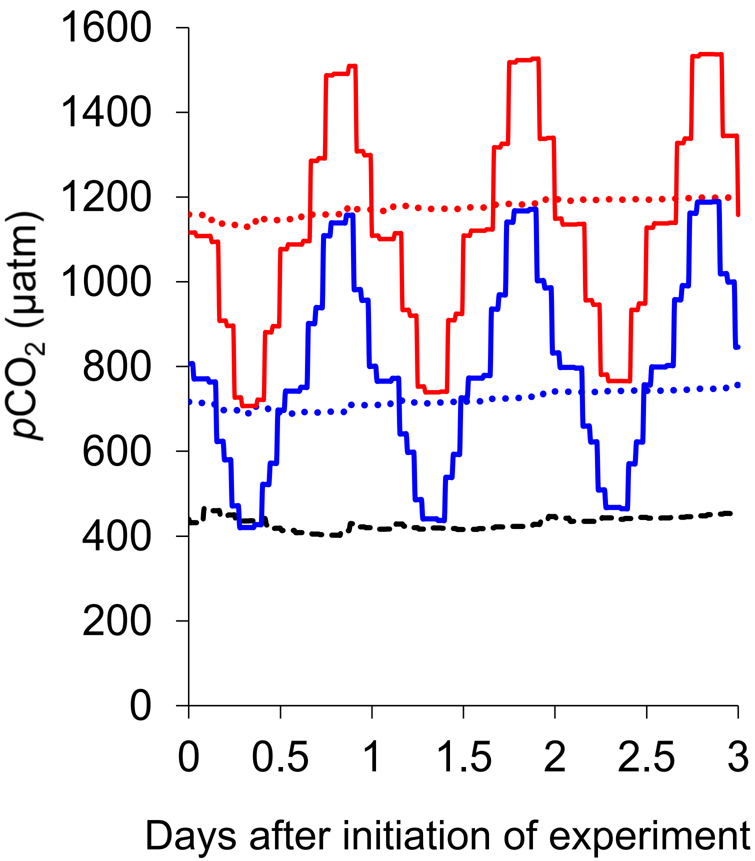
Time series	pH* (yr^{-1})	Reference
BATS	-0.0017 ±0.0001	Bates et al., 2014
ESTOC	-0.0014 ±0.0001	Bates et al., 2014; Gonzàlez-Dàvila et al., 2010
HOT	-0.0017 ±0.0001	Bates et al., 2014; Dore et al., 2009
CARIACO	-0.0024 ±0.0003	Bates et al., 2014; Astor et al., 2013
DYFAMED	-0.0019 ±0.0009	Touratier and Goyet, 2011
MUNDA	-0.0016 ±0.0003	Bates et al., 2014; Currie et al., 2011
KNOT/K2	-0.0024 ±0.0007	Wakita et al., 2013
Station P	-	Wong et al., 2010
137° E section at 10° N	-0.0011 ±0.0001	Midorikawa et al., 2010

*calculated from T, S, Nutrients, DIC and TA



Time series	pH (yr^{-1})
ONJUKU	-0.007
KASHIWAZAKI	-0.011

Effects of diurnally-fluctuating pCO_2 on ezo-abalone larvae by rearing experiment



Constant treatments

Targeted pCO_2

400 µatm, 800 µatm, 1200 µatm

Results of monitoring (Dotted lines)

430 ± 15, 732 ± 19, 1175 ± 20 µatm

Diel cycle treatments

Targeted pCO_2

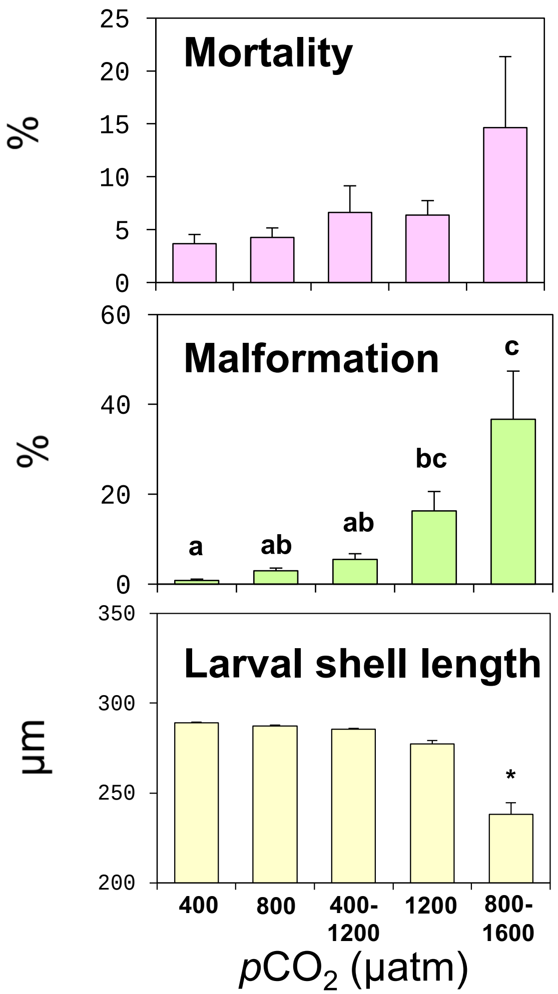
400-1200 µatm, 800-1600 µatm

Results of monitoring (Solid lines)

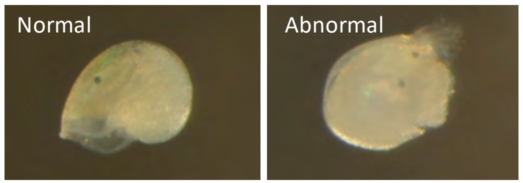
420-1189 µatm, 739-1537 µatm

Onitsuka et al., 2018 Mar. Env. Res., 134, 28-36.

Results : Effects on ezo-abalone larval fitness



Slightly high: 400-1200, 800, 800-1600 μatm

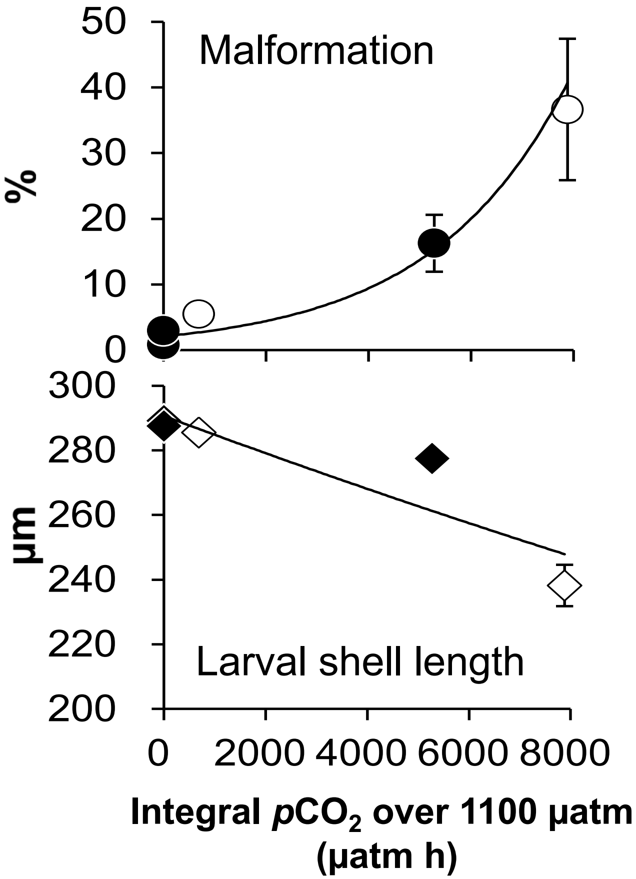


Significantly high:
1200μatm and 800-1600
μatm

Significantly short: 800-1600 μatm

Onitsuka et al., 2018 Mar. Env. Res., 134, 28-36.

Results 2: Effect of “integral pCO_2” on larval fitness



Open circles: incubation with diel cycle pCO2
Solid circles: incubation with constant pCO2

- Malformation rate increased around 1.1 of Ω_{ara} which corresponds to ≅1100 µatm of pCO_2.
- The impacts of OA on growth of larval abalone can be determined by intensity and time of exposure to pCO_2 over the threshold called as “Integral pCO_2 over 1100 µatm”.
- Integral pCO_2 over 1100 µatm

$$=\sum(P-1100)i$$

P: pCO_2 over 1100 µatm
i: exposed hours to pCO_2 over 1100 µatm

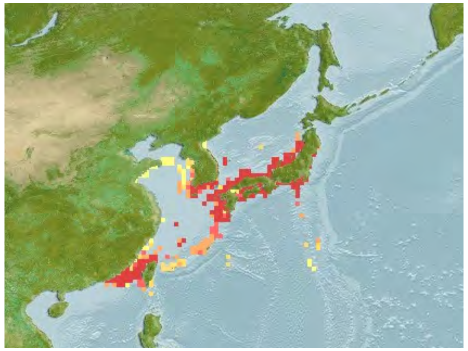
- Larval shell length decreased with the increasing of integral pCO_2 over 1100 µatm.

Onitsuka et al., 2018 Mar. Env. Res., 134, 28-36.

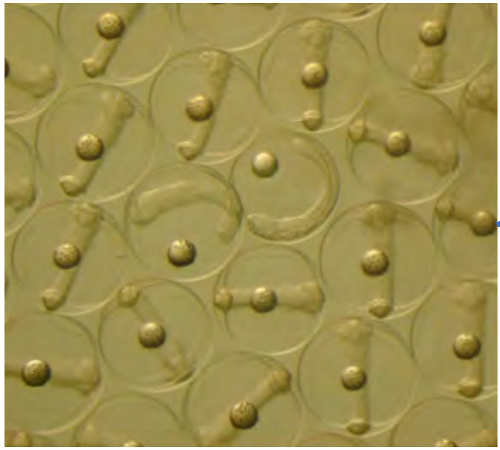
Sillago japonica

Model marine-fish for pollutant contamination tests

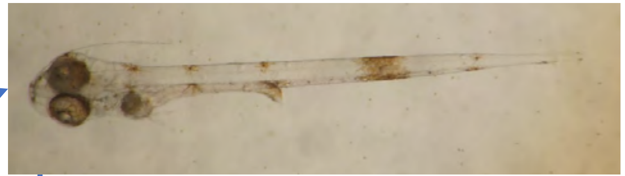
Maximum Size: 30 cm
Range: Temperate zone of Japanese coast
Important fish for fisheries industry



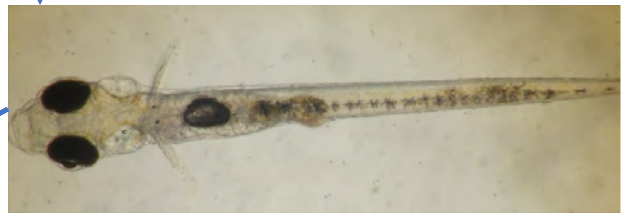
Early life development of *S. japonica*



Egg diameter ca. 700 µm



1 days after hatch, TL 2.7 mm



3 days after hatch, TL 3.0 mm

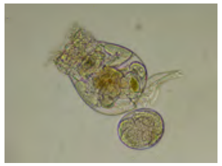
8 days after hatch, TL 4.5 mm

15 days after hatch, TL 8.0 mm

38 days after hatch, TL 30 mm

Rearing system for larval *S. japonica*

Phytoplankton:
Tetraselmis tetrathele and *Pavlova lutheri*

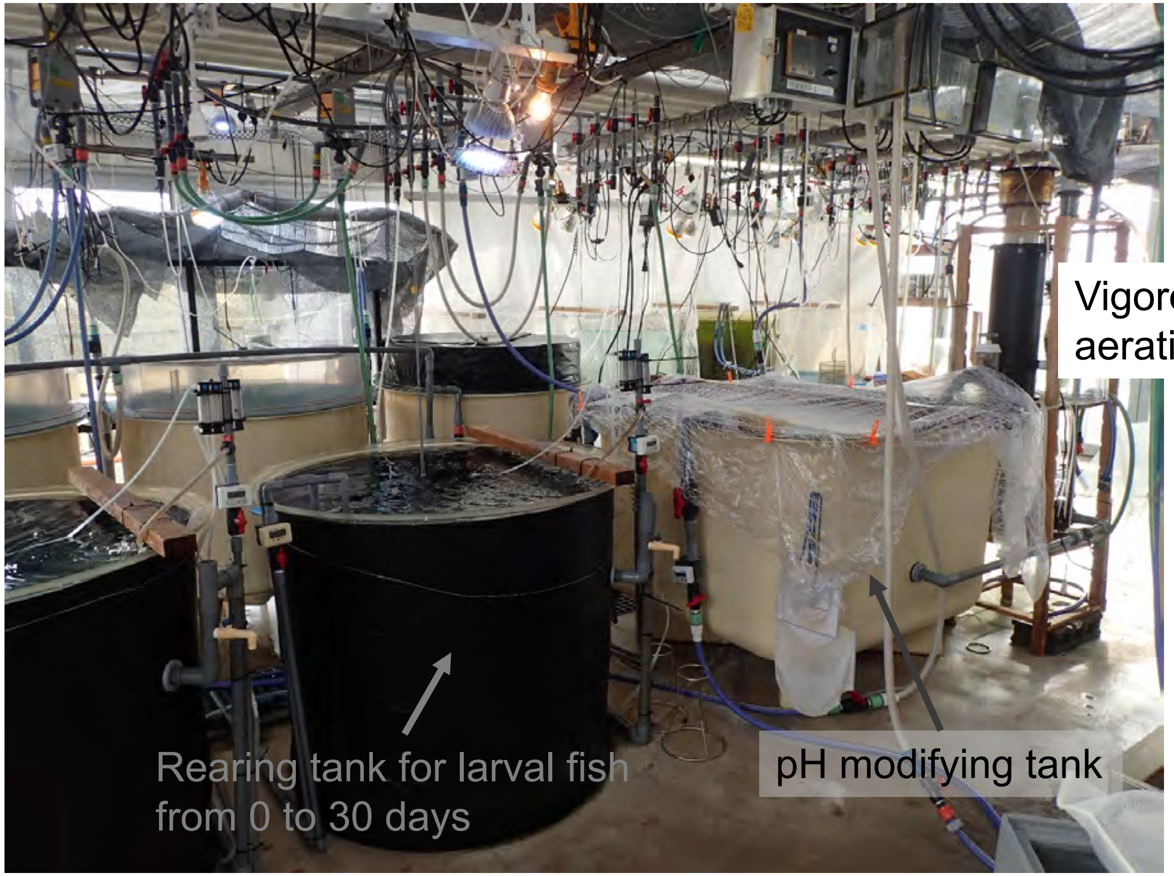


Zooplankton:
Branchionus plicatilis sp. complex

Fish rearing tank

Temp: 26℃
Sal: 32.5
Total alkalinity: 2250μmol/kgsw

Rearing experiments of larval *S. japonica* with different pH condition



Tank 1:
Initial pH: 8.09
Without pH control during experiment

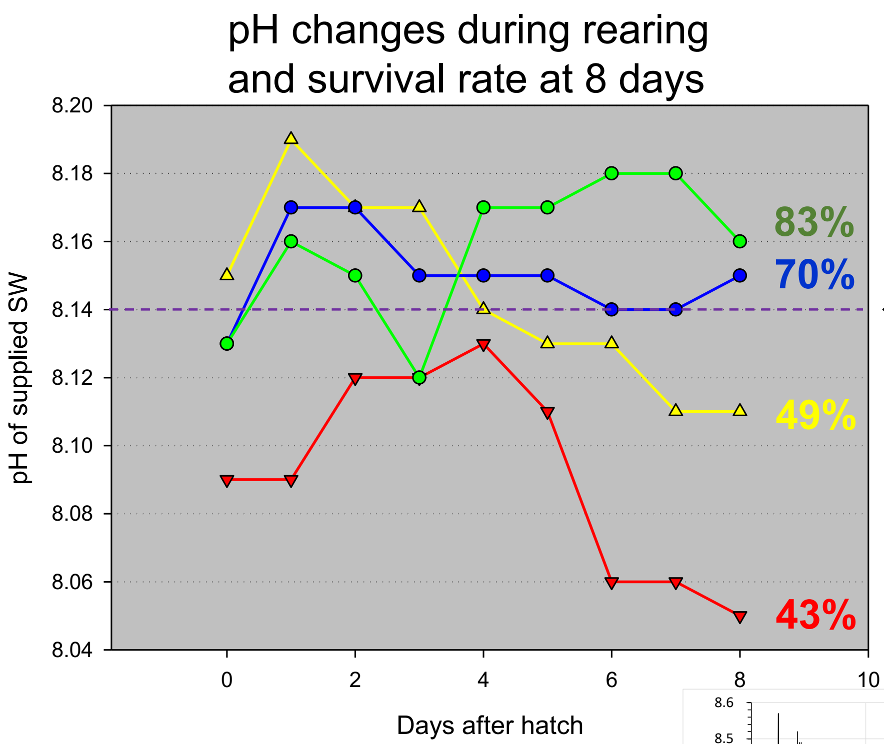
Tank 2:
Initial pH: 8.15
Without pH control during experiment

Tank 3:
Initial pH: 8.13
With slightly pH controlled using water passed through the pH modifying tank by aeration to make pCO_2 equal to pCO_{2air}

Tank 4:
Initial pH:8.13
With slightly pH controlled using water passed through the pH modifying tank by aeration to make pCO_2 equal to pCO_{2air}

Inflow with pH 8.05 (pCO_2 580 µatm) → pH modifying tank → Outflow pH 8.18 (pCO_2 400 µatm)

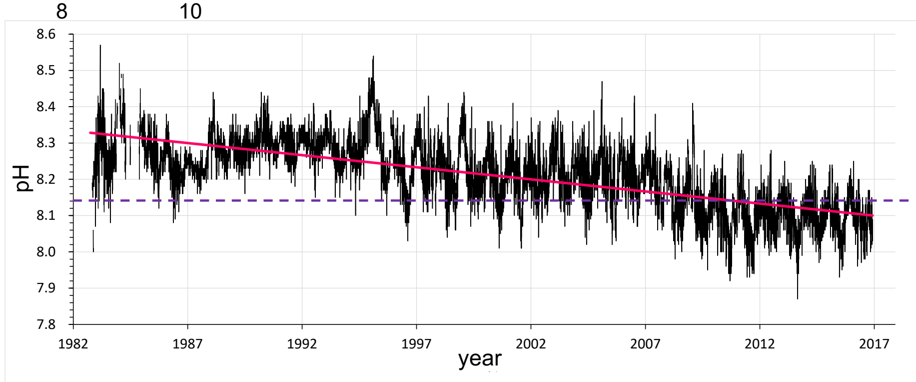
Impacts of change in pH on larval *S. japonica*



pH threshold ??

"Threshold" is also important for juvenile's survival of *Sillago japonica?*

Note: pH is that of inflow water of tank (water inside the tank was not taken for pH monitor because the larval *S. japonica* is very delicate)



pH threshold ??

Summary

- Subsurface pH in the western Arctic Ocean observed from Sep 2015 to Sep 2016 showed large seasonality with dynamic range of 0.5 pH unit. The pH largely dropped in summer and the beginning of sea-ice seasons.
- Pteropods shell density decreased maximum 40% responding to the reduction of aragonite saturation degree (Ωara) during summer and the beginning of sea-ice seasons in the western Arctic Ocean.
- At Japanese coastal stations, the annual pH reduction rate was -0.007 and-0.011 at the Pacific and Japan Sea sides, respectively. These are twice or three times larger than those of monitoring sites in pelagic oceans.
- Popular commercial organisms, ezo-abalone and *Sillago japonica* responded to ocean acidification. Rearing experiments showed that their juvenile received immediately negative impact when the pH (or Ωara or pCO_2) drops under the threshold.
- Adaptation strategies for marine organisms such as seed production of commercially important fish are necessary to overcome progress in future ocean acidification.