Calcium carbonate saturation state and ocean acidification in Tokyo Bay, Japan

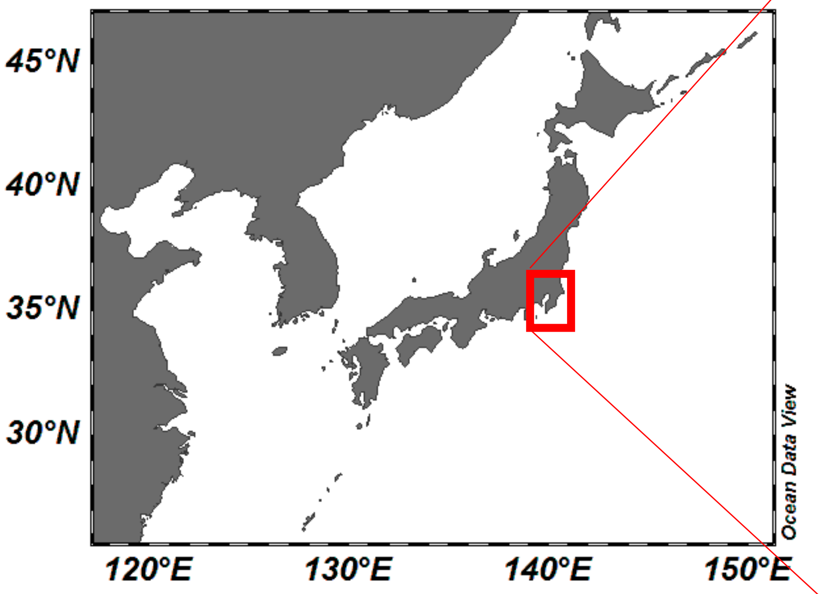
Michiyo Yamamoto-Kawai

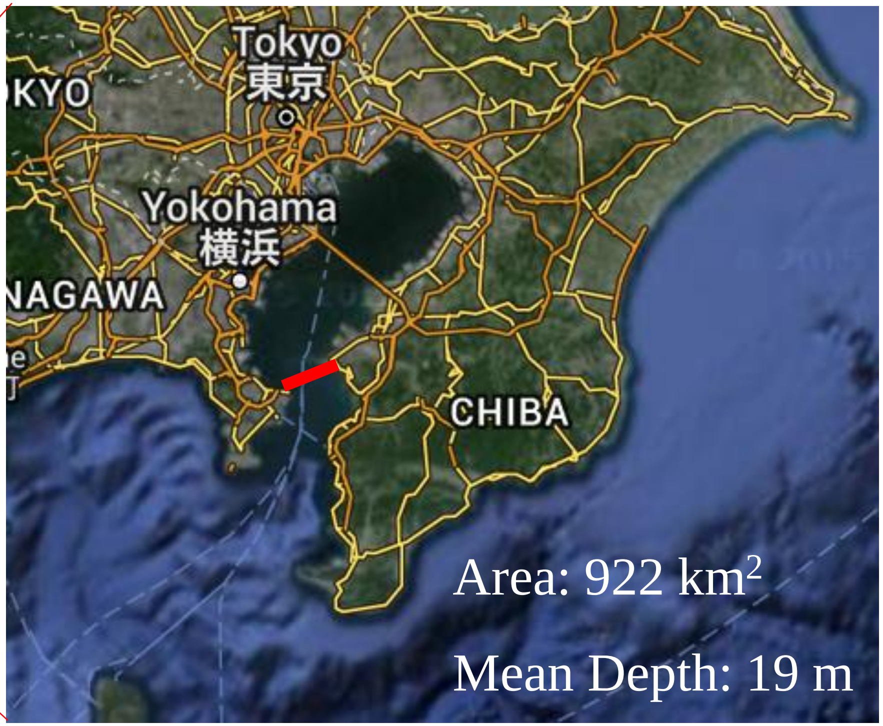
(TUMSAT)

Natsuko Kawamura, Tsuneo Ono, Naohiro Kosugi,

Atsushi Kubo, Masao Ishii, and Jota Kanda

Tokyo Bay

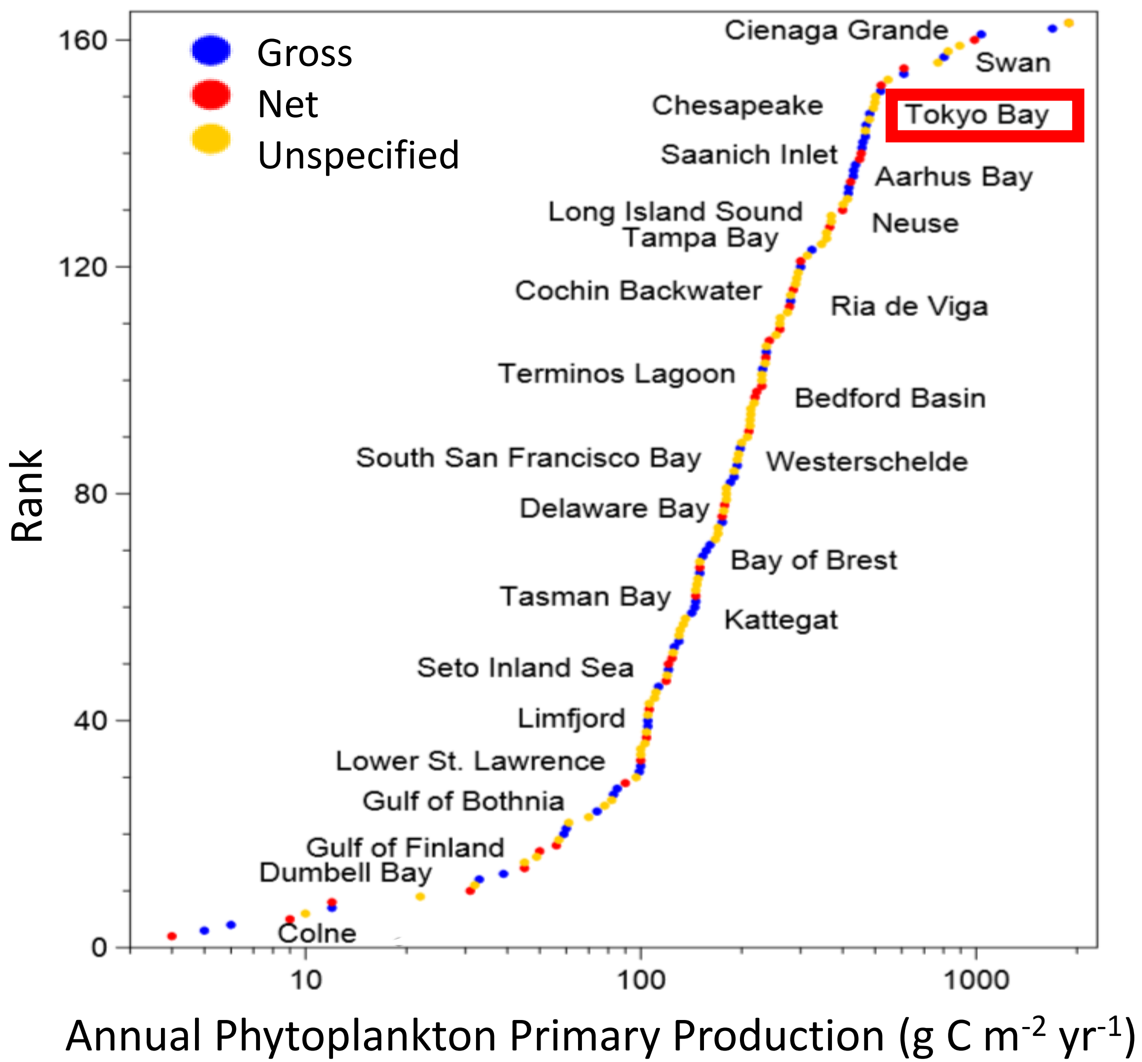




- Shallow, semi-enclosed bay
- Surrounded by highly urbanized areas
- Receives freshwater and nutrients from rivers and sewage treatment plants
- One of the most eutrophicated coastal environments in the world

Tokyo Bay

ranked distribution of Primary Production



[Cloern et al., 2014]

Red tide
Blue tide
Hypoxic water

Ocean acidification could give an additional stress to the ecosystem of the bay

First observations of Ω in Tokyo Bay, from 2011 to 2012

[Yamamoto-Kawai et al., Journal of Oceanography, 2015]

Questions

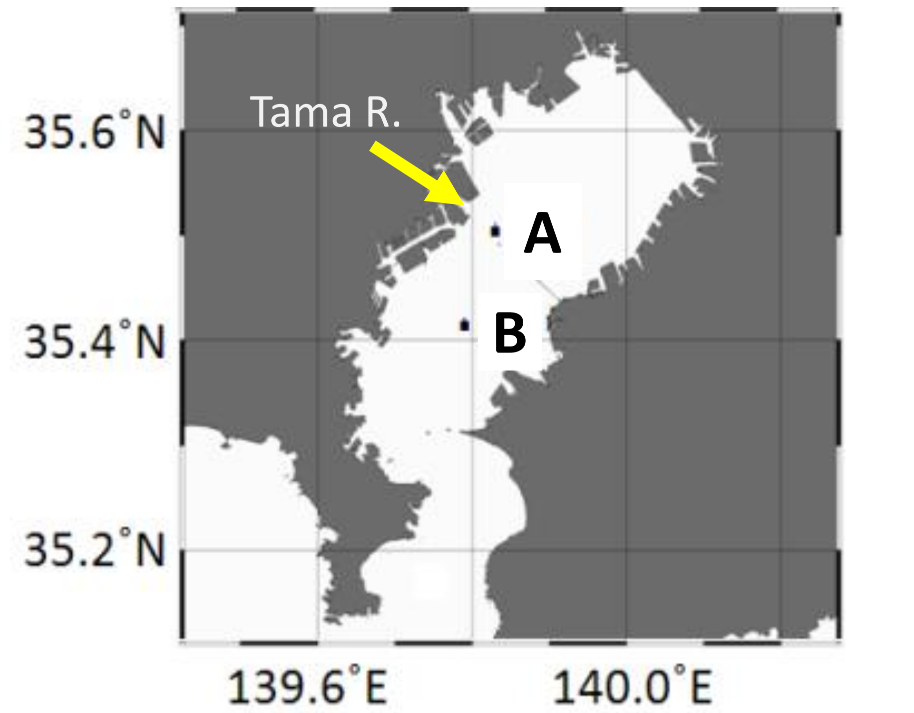
- Is $\Omega_{aragonite}$ already < 1 in Tokyo Bay? If not, when will it be reached?
- How does Ω change seasonally?
- What are factors controlling seasonal variation of Ω in Tokyo Bay?
- How much did human activity change Ω?

Observations

April 2011～January 2012（every month）

Stations
A: 23m, Innermost bay
B: 26m, Middle bay

Sampling and analysis
CTD-Rosette, RINKO-O_2
→ DIC, TA, Nutrients and Chl.a

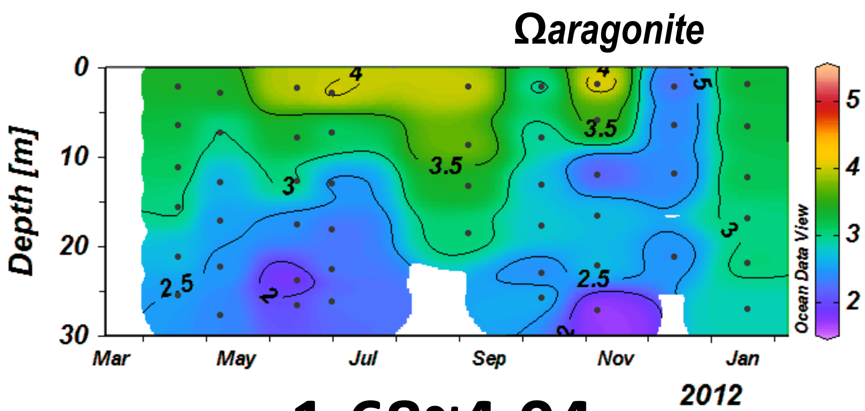


Ω and pCO_2 : CO2sys program

(K_1 and K_2: Lueker et al., 2000; KSO_4: Dickson, 1990)

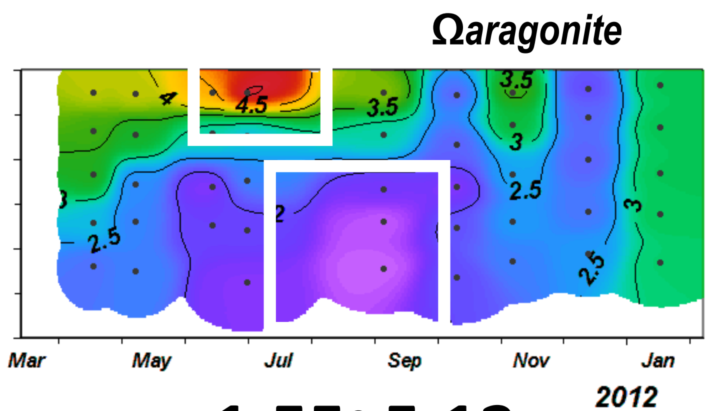
$\Omega_{aragonite}$

Sta. B (Middle bay)



1.68~4.04

Sta. A (Innermost bay)

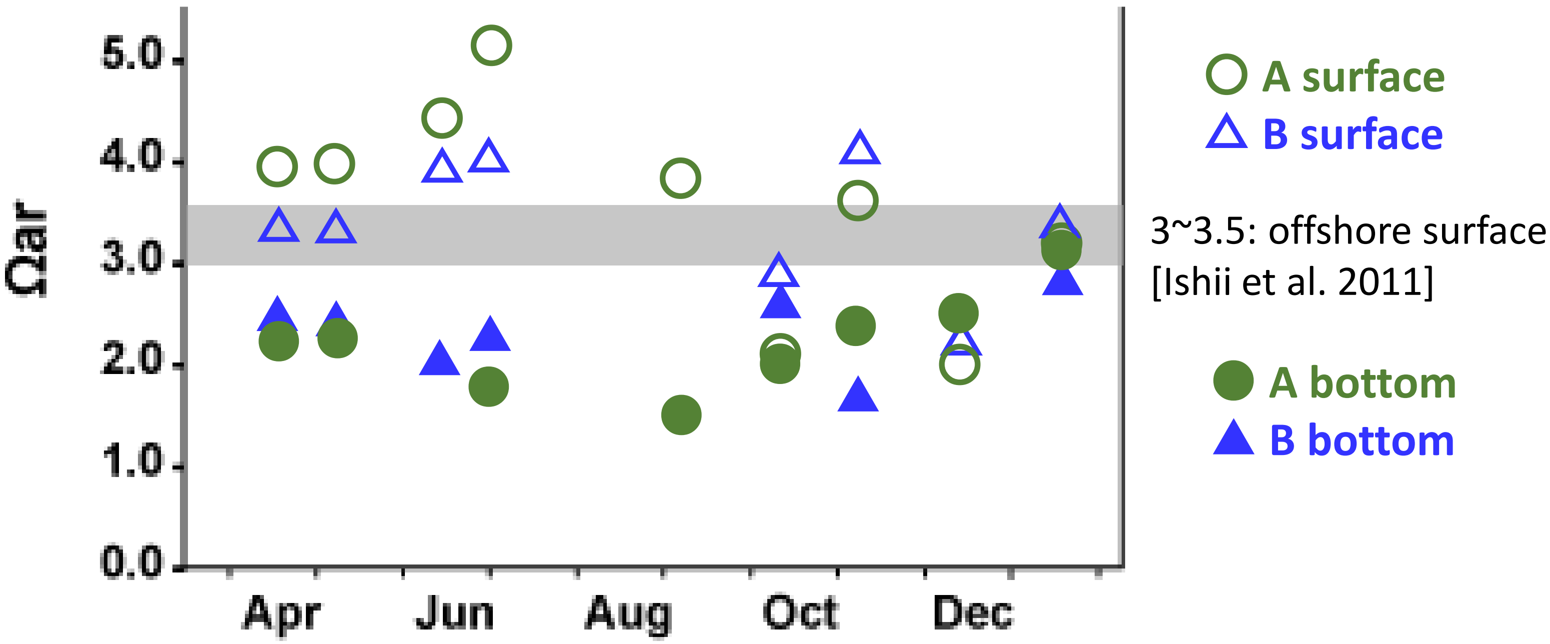


<u>1.55</u>~<u>5.12</u>

- Is $\Omega_{aragonite}$ already < 1 in Tokyo Bay? -NO!

$\Omega_{aragonite}$

- How does Ω change seasonally?
- **<u>What are factors controlling seasonal variation of Ω in Tokyo Bay?</u>**



○ **A** surface: 2.01 (Dec)～5.12 (Jun) ⊿**3.11**

△ **B** surface: 2.27 (Dec)～4.04 (Nov)⊿**1.77**

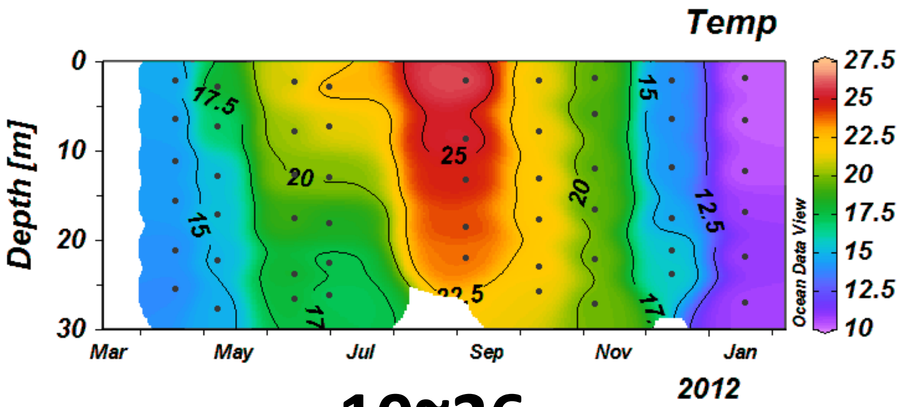
● **A** bottom: 1.55 (Sep)～3.07 (Jan) ⊿**1.52**

▲ **B** bottom: 1.68 (Nov)～2.85 (Jan)⊿**1.17**

<u>Larger variation at Sta. A (Innermost Bay) than B (Middle Bay)</u>

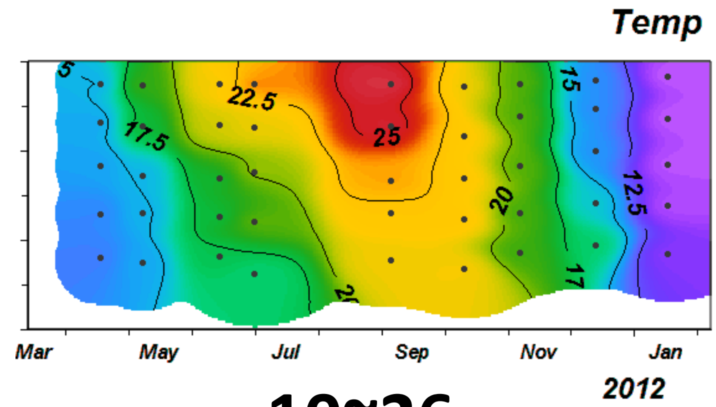
Temperature & Salinity

Sta. B (Middle Bay)

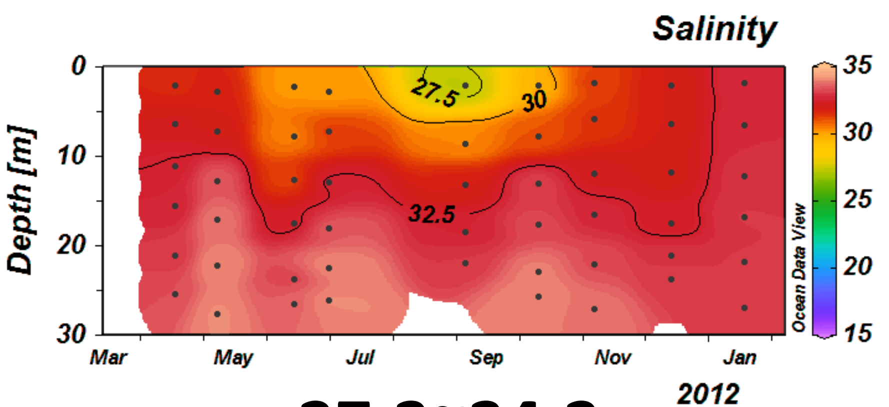


10~26

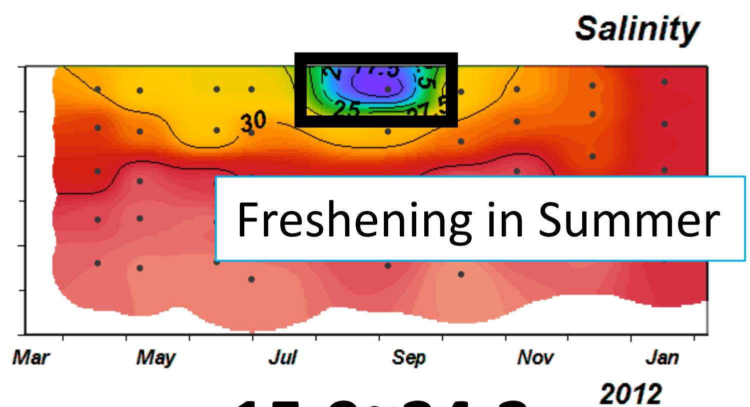
Sta. A (Innermost Bay)



10~26



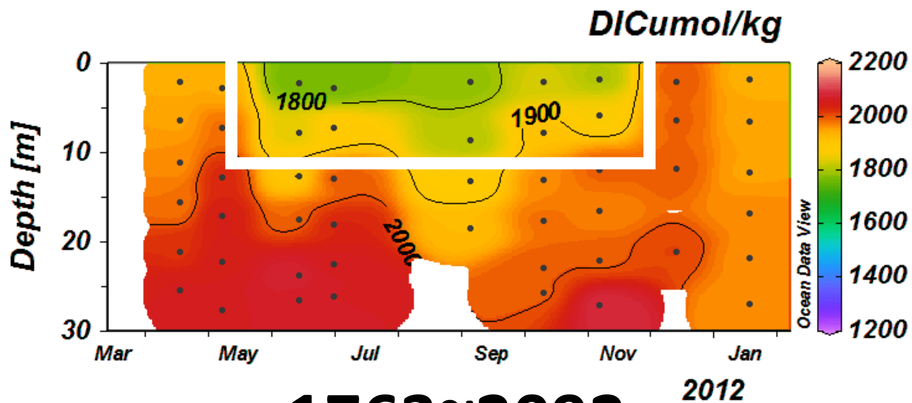
27.3~34.2



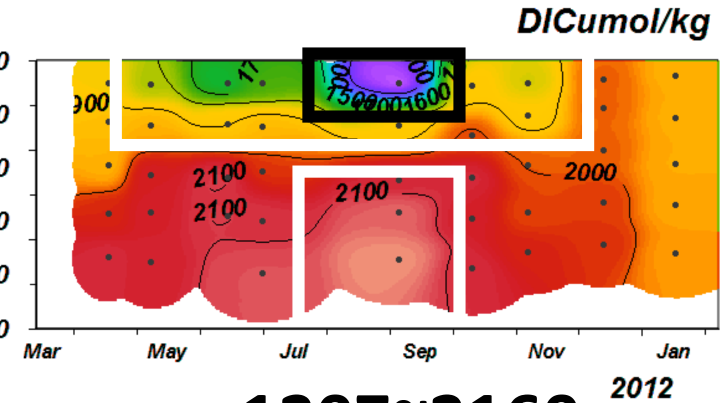
<u>15.9</u>~34.3

DIC & TA

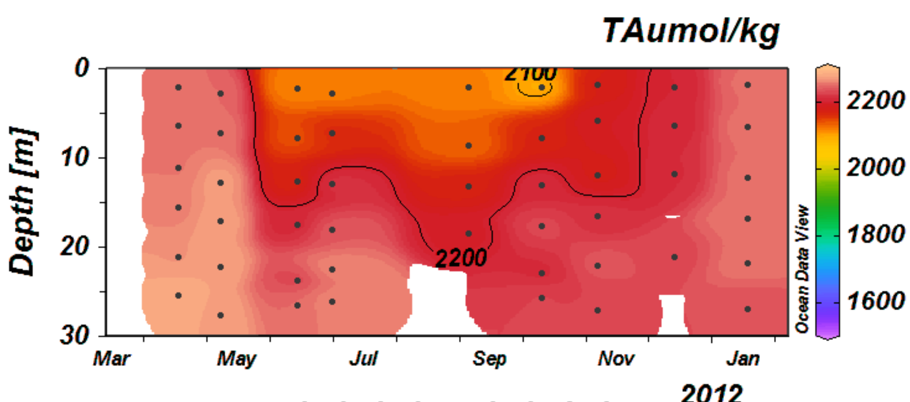
Sta. B (Middle Bay)	Sta. A (Innermost Bay)



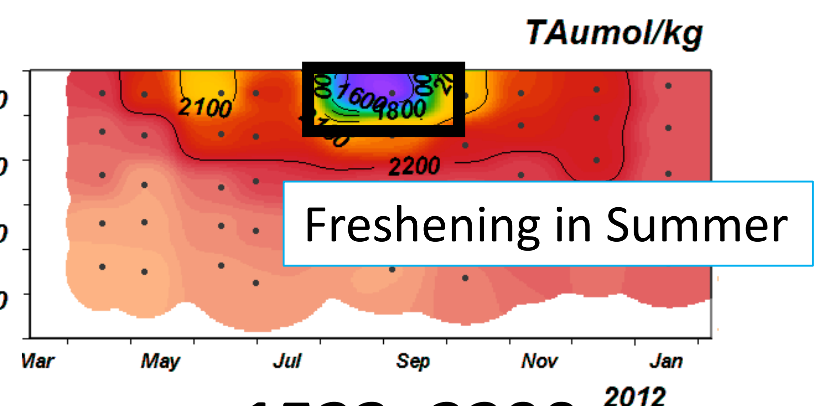
1763~2092



<u>1207</u>~<u>2160</u>



2092~2283

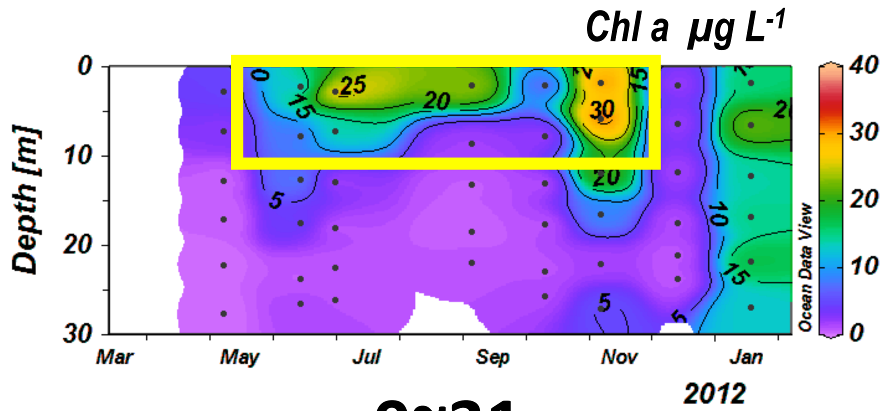


<u>1523</u>~2290

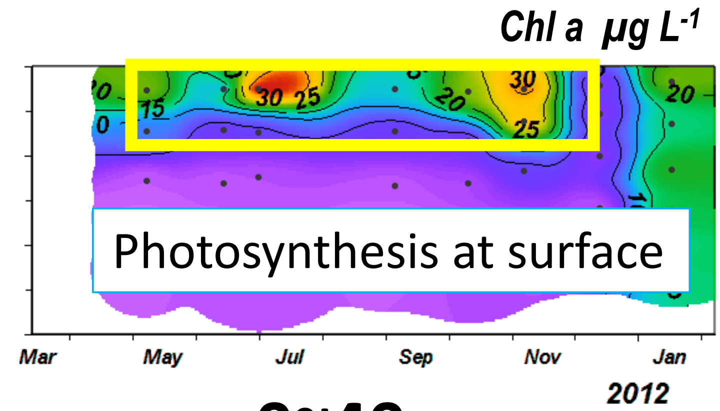
Chlorophyll *a* & DO %

Sta. B (Middle Bay)

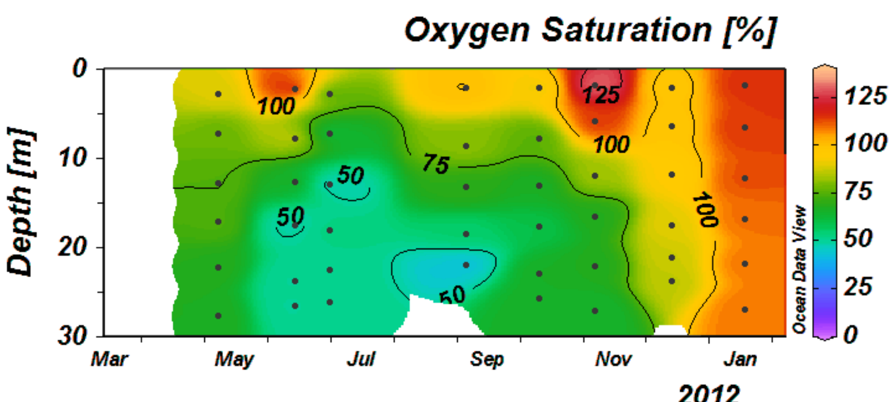
Sta. A (Innermost Bay)



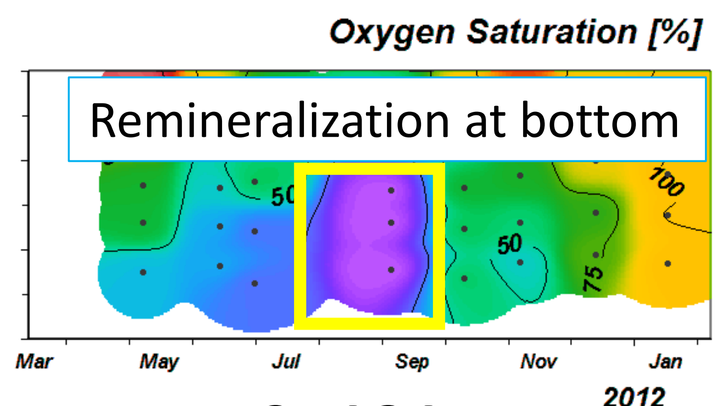
0~31



0~40



43~131

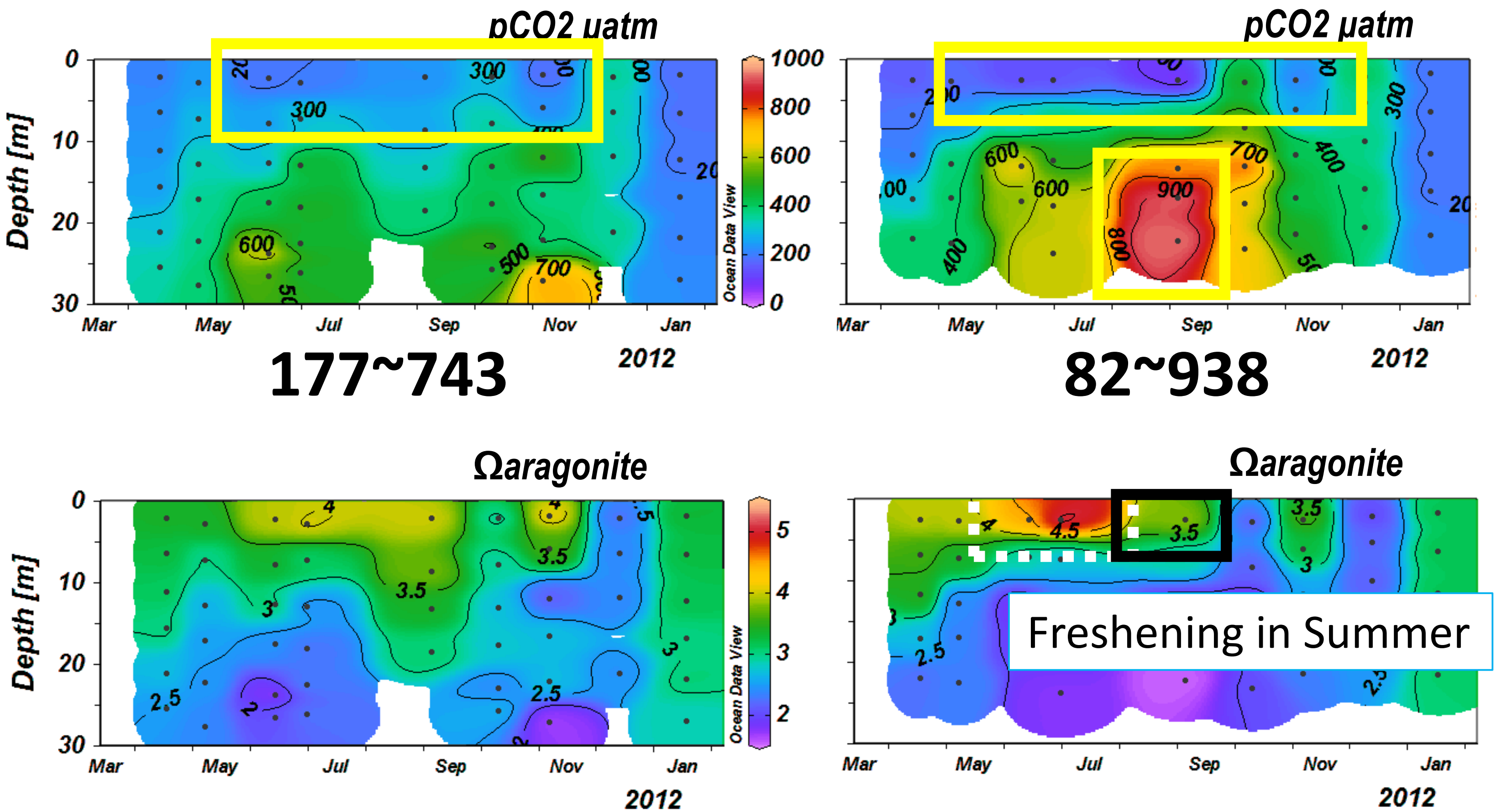


2~131

pCO_2 & $\Omega_{aragonite}$

Sta. B (Middle Bay)

Sta. A (Innermost Bay)



177~743

82~938

1.68~4.04

1.55~5.12

- What are factors controlling seasonal variation of Ω in Tokyo Bay?
  - Freshwater input (surface) Sta. A >> Sta. B
  - Photosynthesis (surface) Sta. A > Sta. B
  - Remineralization (bottom) Sta. A >> Sta. B

  Innermost bay has lower Ω and larger seasonal variability

- How much did human activity change Ω in Tokyo Bay?

  1. Freshwater regulation

  2. Eutrophication

  3. Anthropogenic CO_2

Freshwater regulation

Freshwater input to Tokyo Bay

341 $m^3 s^{-1}$ in 1947-1974 → 424 $m^3 s^{-1}$ in 2002-2003

24 % up

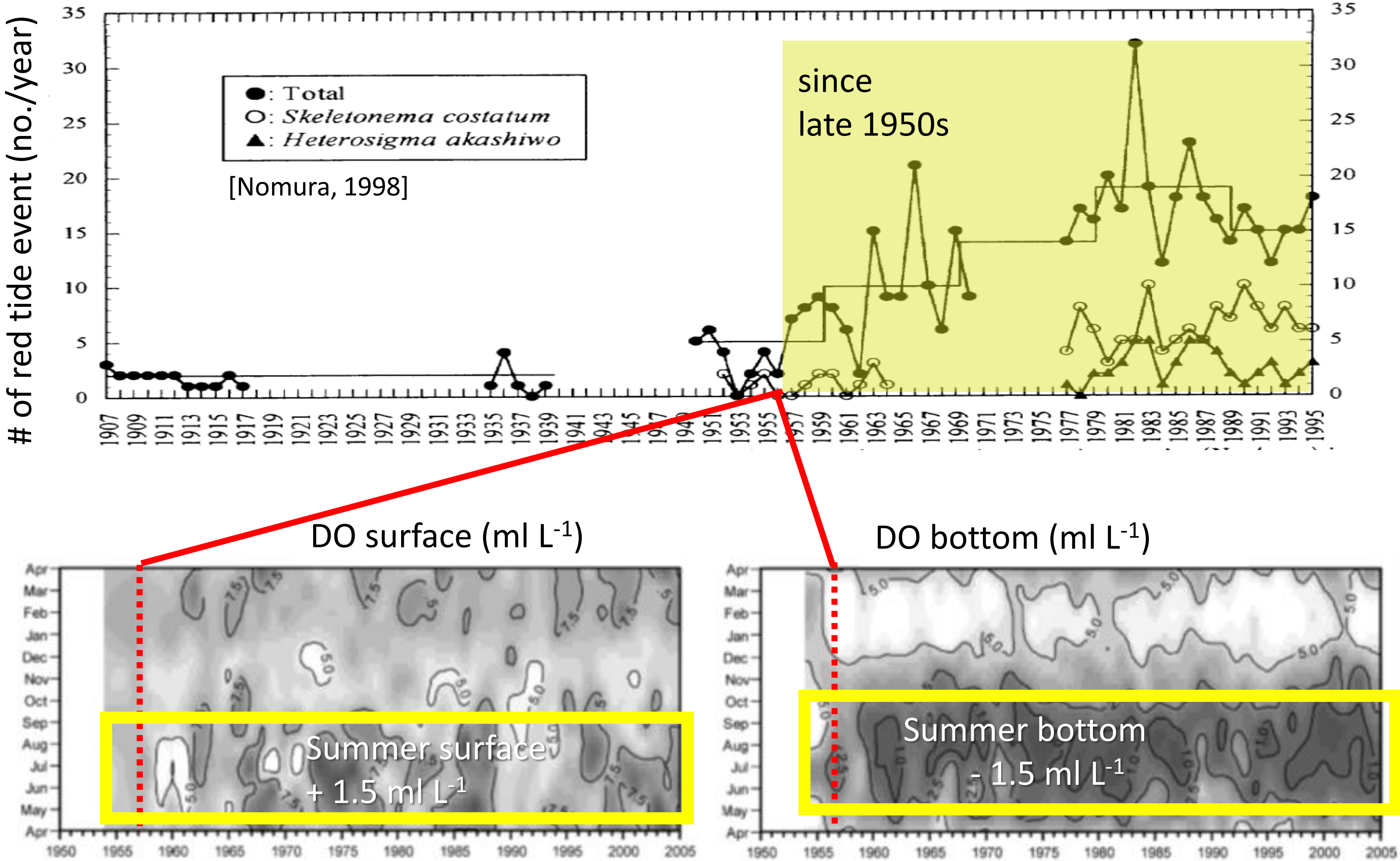
introduction of freshwater to the metropolitan region

from outside of the drainage basins [Okada et al., 2007]

$\Omega_{w/o\text{-}FW}$ from $S_{w/o\text{-}FW}$ $TA_{w/o\text{-}FW}$ $pCO_{2\text{-}obs}$ and T_{obs}

Increased FW might have lowered Ωar by up to 0.3

Eutrophication



[Ishii et al, 2008]

Eutrophication

Δ DO +/- 1.5 ml L^{-1} (67 µmol kg^{-1}) = ΔDIC -/+ 46 µmol kg^{-1}

→ $\Delta\Omega$ar +/- 0.45 (O_2:C = -170 : 117)

Eutrophication

has increased Ωar by 0.45 in summer surface water

has decreased Ωar by 0.45 in summer bottom water

$\Delta\Omega$ar +/- 0.4 ~ 0.6 (O_2/C = 1~1.58; Fraga et al. 1998)

Anthropogenic CO_2

$$DIC = C_{EQ} + (\Delta C_{Diseq} + \Delta C_{Bio})$$

C_{EQ} DIC in equilibrium with atmospheric CO_2 (280 vs 400 ppm)

ΔC_{Diseq} air-sea disequilibrium

ΔC_{Bio} biological activity

(cf. Gruber et al. 1996; Sabine et al. 2002; Yamamoto-Kawai et al. 2013)

Increased atmospheric CO_2 from 280 to 400 ppm alone could have decreased Ωar by 0.6

- How much did human activity change Ω?

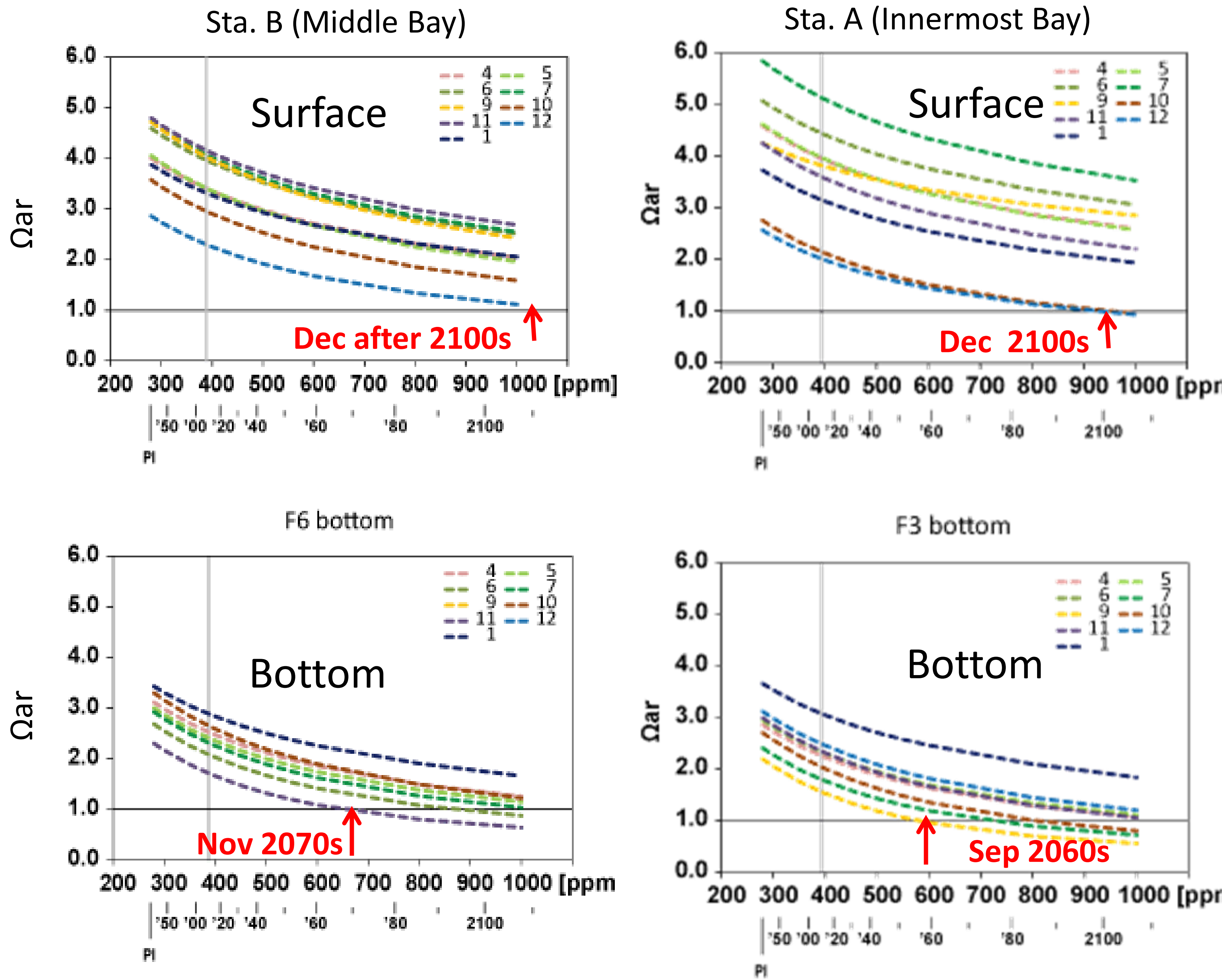
    1. Freshwater regulation -0.3

    2. Eutrophication +/- 0.45 surface/bottom

    3. Anthropogenic CO_2 -0.6

- When will $\Omega_{aragonite} < 1$ be reached?

$$DIC = C_{EQ} + (\Delta C_{Diseq} + \Delta C_{Bio})$$



Sta. B (Middle Bay)
Surface
Ωar
Dec after 2100s
200 300 400 500 600 700 800 900 1000 [ppm]
'50 '00 '20 '40 '60 '80 2100
PI
Sta. A (Innermost Bay)
Surface
Dec 2100s
F6 bottom
Bottom
Nov 2070s
F3 bottom
Sep 2060s
4 5 6 7 9 10 11 12 1

Summary and conclusions

- $\Omega_{aragonite}$ varied from 1.55 to 5.12 in the innermost bay in 2011/2012
- Seasonal variation of $\Omega_{aragonite}$ was much larger than in offshore waters
- Freshwater regulation, eutrophication and anthropogenic CO_2 have changed $\Omega_{aragonite}$ by 0.3 (-), 0.45 (+/-) and 0.6 (-), respectively
- Bottom water in innermost bay will reach seasonal aragonite saturation by 2060s (~50yrs earlier than offshore)

!! These are based on one-year observation and rough assumptions !!

- **Need to continue our observation in Tokyo Bay, as well in other coastal regions of Japan**
- **Assessment of OA impact on organisms in each region is also required**

Japan Coastal Ocean Acidification Project (JACOA)

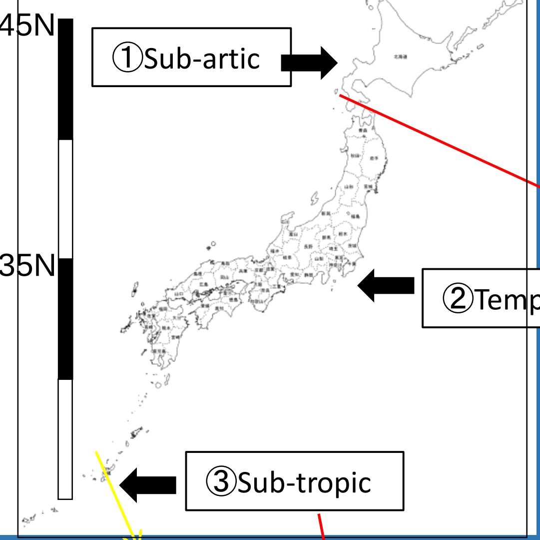
Haruko Kurihara* (University of the Ryukyus)

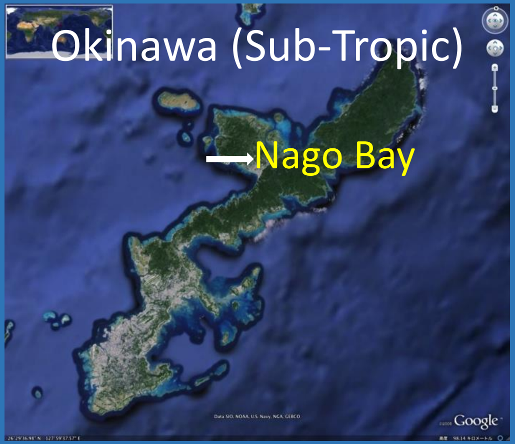
Michiyo Yamamoto-Kawai (Tokyo University of Marine Science and Technology)

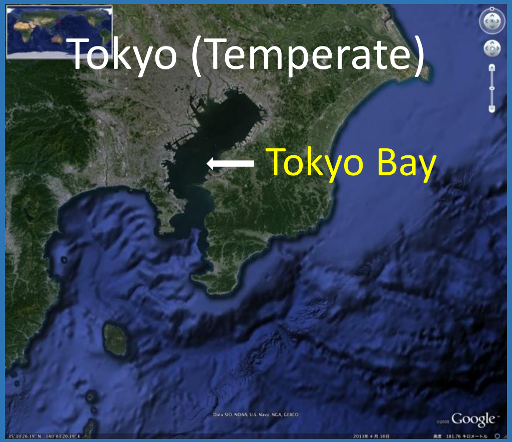
Masahiko Fujii (Hokkaido University)

*harukoku@sci.u-ryukyu.ac.jp

1. Monitoring pH in 3 different latitude regions

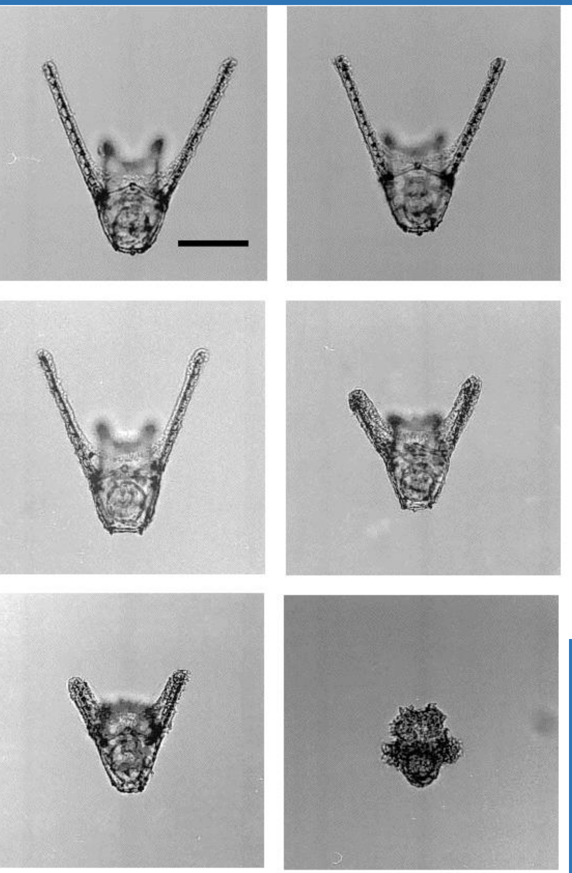




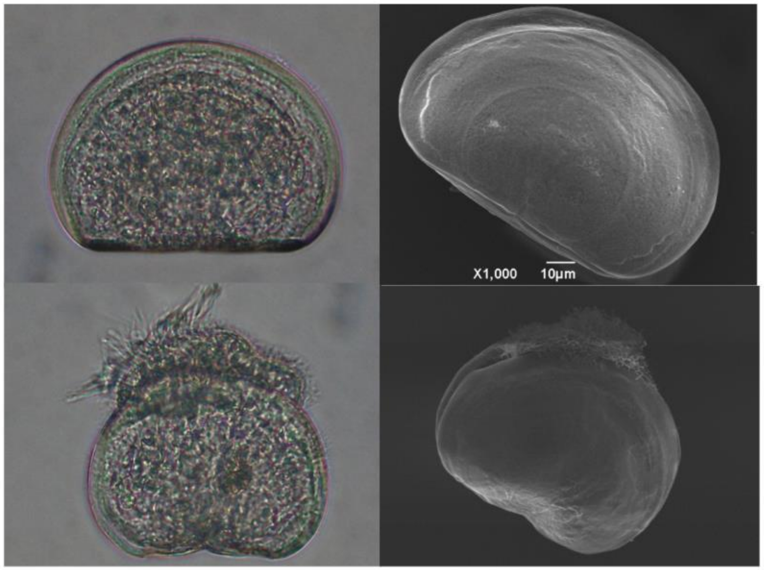


Monthly observations of DIC/TA, T, S
pH sensor

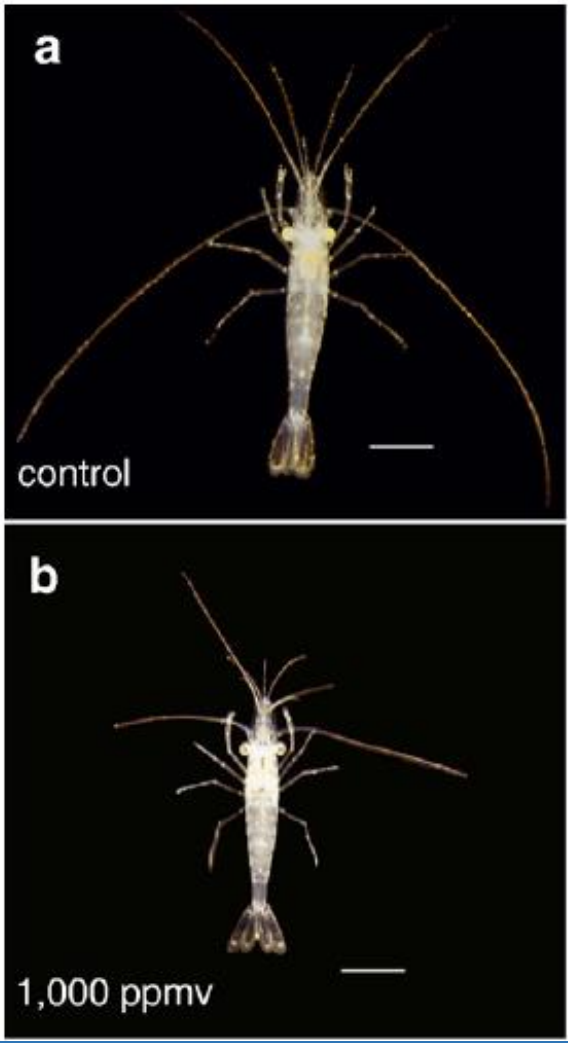
2. Evaluating effects on the fisheries



Kurihara et al 2004
Kurihara & Shirayama 2004



Kurihara et al. 2008



Kurihara et al 2007