Effect of marine heatwaves on the bloom of harmful dinoflagellate *Cochlodinium polykrikoides* in Korean coastal waters : Two sides of the same coin?

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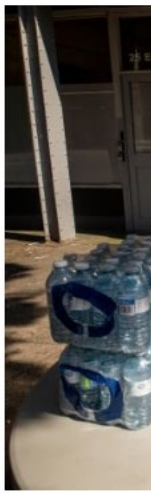
❑ Heatwaves in 2021

Temperatures i
US reached rec

Source: BBC Weather

British Columbi

595 peop
new figu



More than 231
temperatures,

Rhianna Schmunk

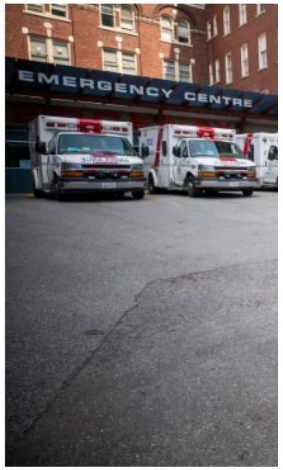
A woman hands ou
June 28 during the 'heat dome' that led to record-breaking temperatures across B.C. (Ben Nelms/CBC)

British Columbia

70% of sudden de
wave were due to
confirms

570 of the 815 deaths deeme
died were 65 or older

CBC News · Posted: Jul 29, 2021 7:52



A paramedic outside St. Paul's Hospit
815 sudden deaths recorded over June's week-long heat wave — 70 per cent — have now been deemed 'heat related.' (Ben Nelms/CBC)

Heat Wave Killed An Estimated 1 Billion Sea Creatures, And Scientists Fear Even Worse

July 9, 2021 · 4:40 PM ET

DEEPA SHIVARAM

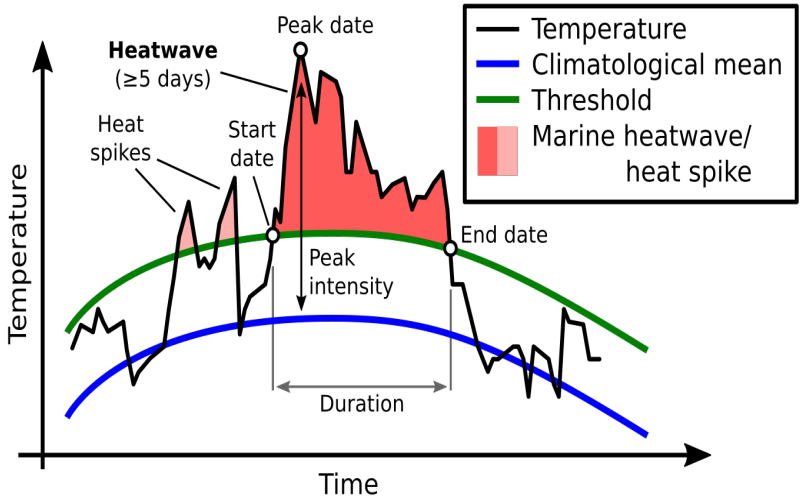
Mussels dying off at such a high rate will have a massive effect on both marine and terrestrial animals, biologists say.
Christopher Harley/University of British Columbia

Christopher Harley/University of British Columbia

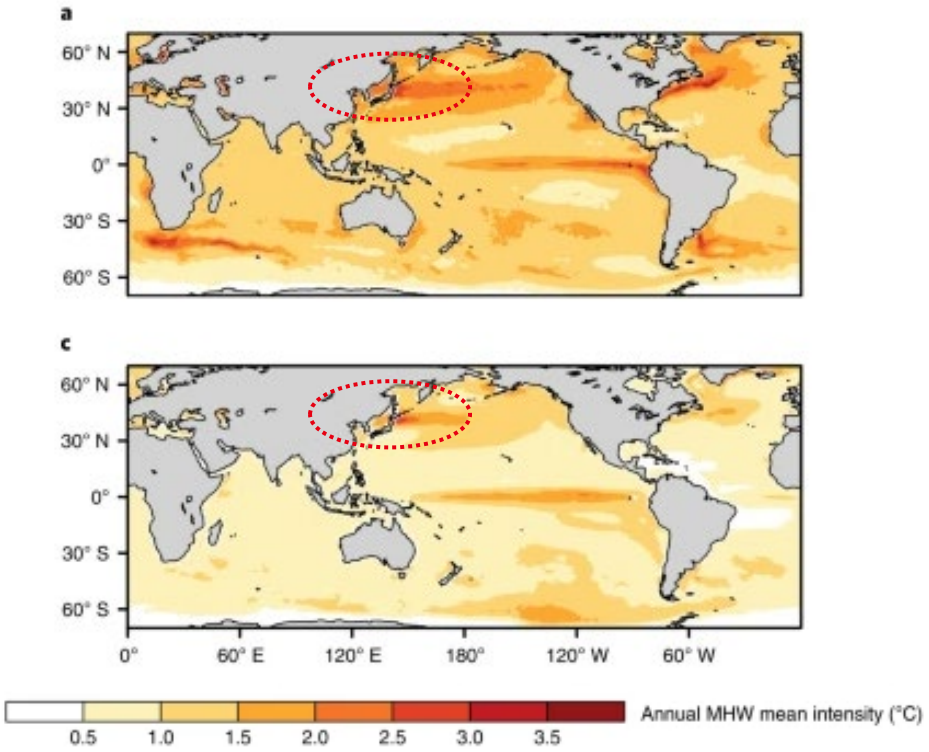
BBC

❑ Marine heatwaves (MHWs)

- Marine heatwaves cause an excessively hot weather in the ocean
- The intensity of marine heatwaves is strong in Northwest Pacific, around Korea

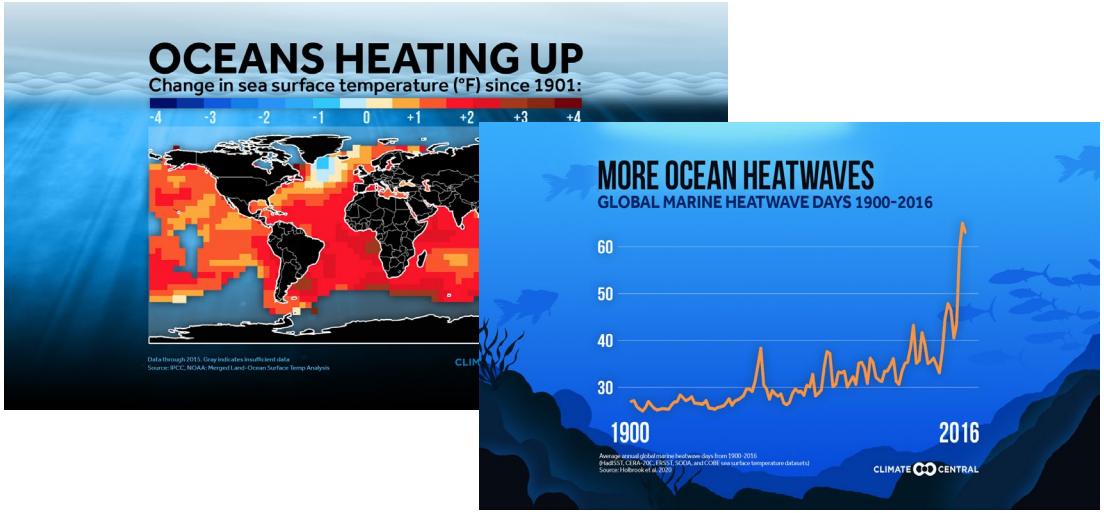


(Hobday et al. 2016).



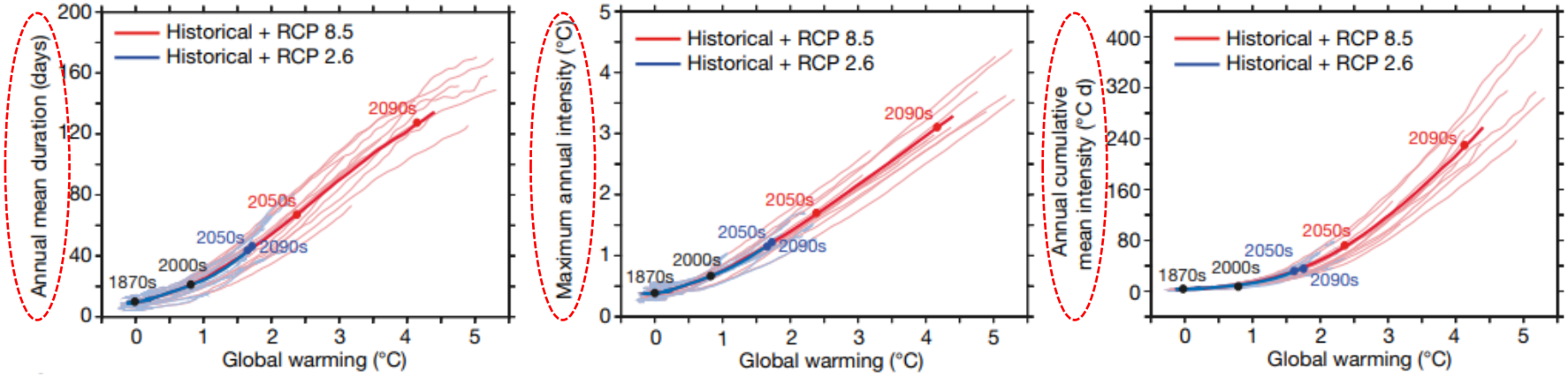
(Guo et al., 2022)

❑ Global warming and MHWs



- In recent decades, MHWs have become **more long-lasting, frequent and intense**, and this trend is expected to accelerate with global warming (Froticher et al. 2018)

http://www.marineheatwaves.org/



(Frölicher *et al.*, 2018)

❑ Impacts of MHWs on marine organisms

- In Western Australia in 2011, the dominant macroalgal species changed **from kelp forests to seaweed turfs after MHWs** (Wernberg et al. 2016).
- In 2015/16, the MHWs led to **massive mortality of abalone** in southeastern Australia (Tasmania) (Roberts et al., 2019; Sanford et al., 2019)
- In 2022, MHWs caused the death of macroalgae forests in Jeju island of Korea
- However, few studies have been conducted on the effect of MHWs on **HABs dynamics**

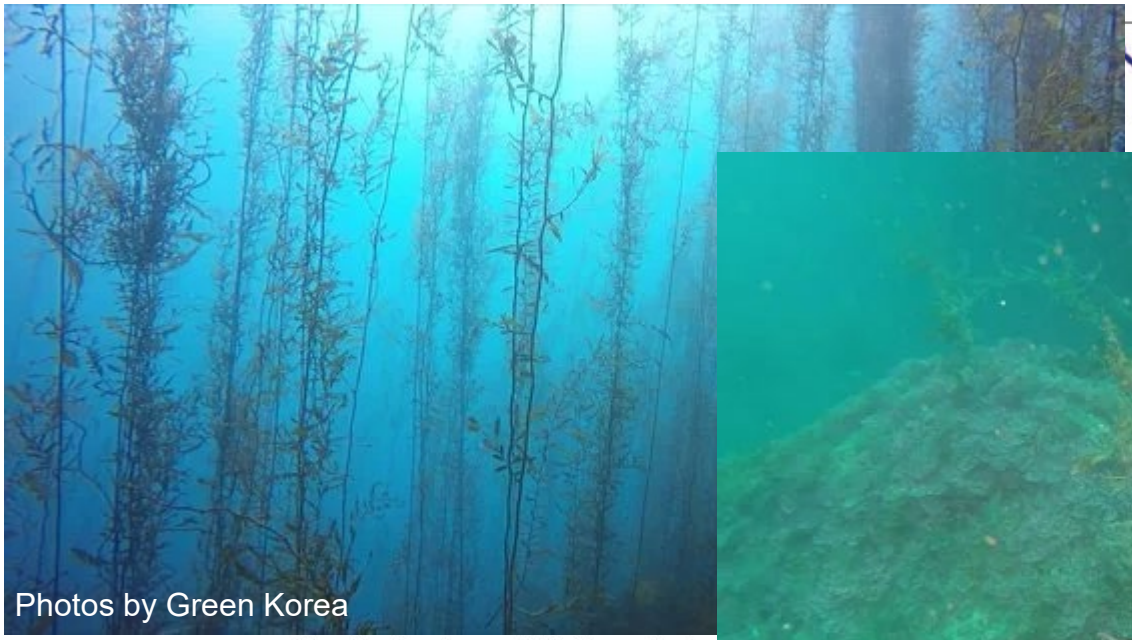
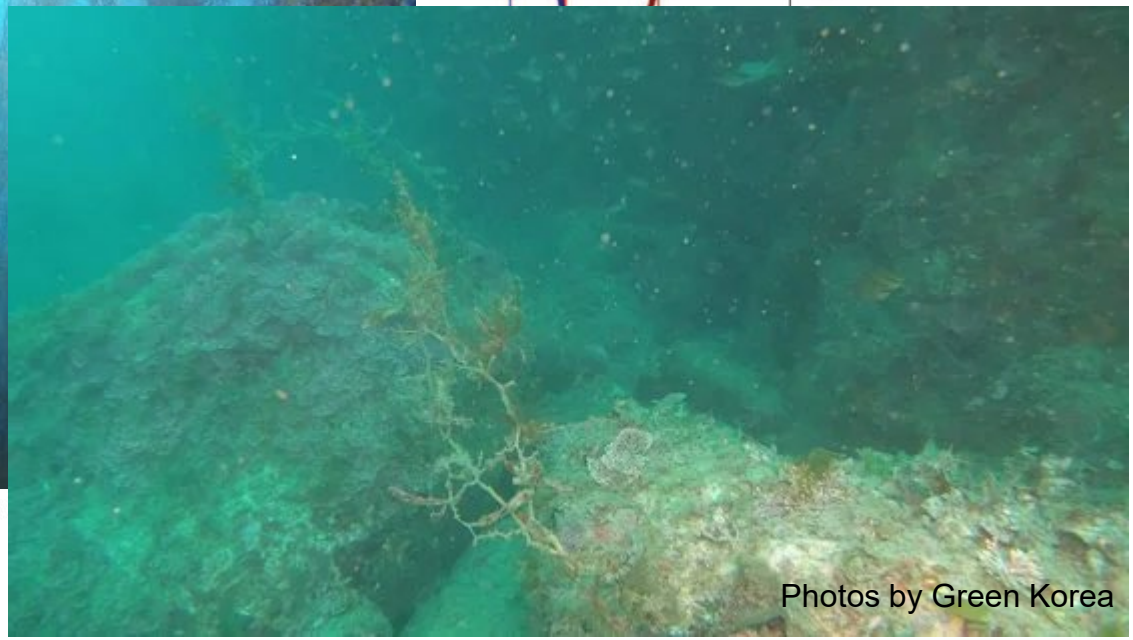


Fig. 2. Regime shift from kelp

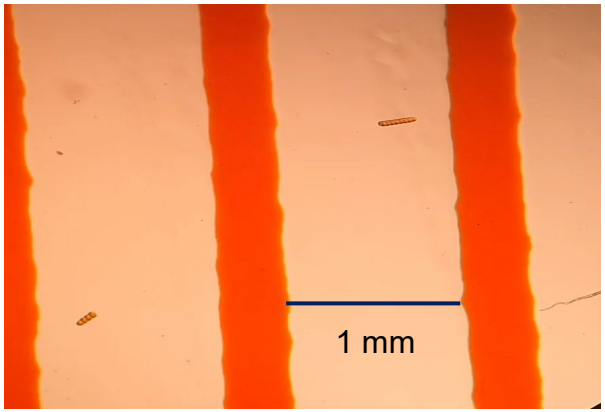


Introduction

❑ Harmful dinoflagellate *Cochlodinium polykrikoides*

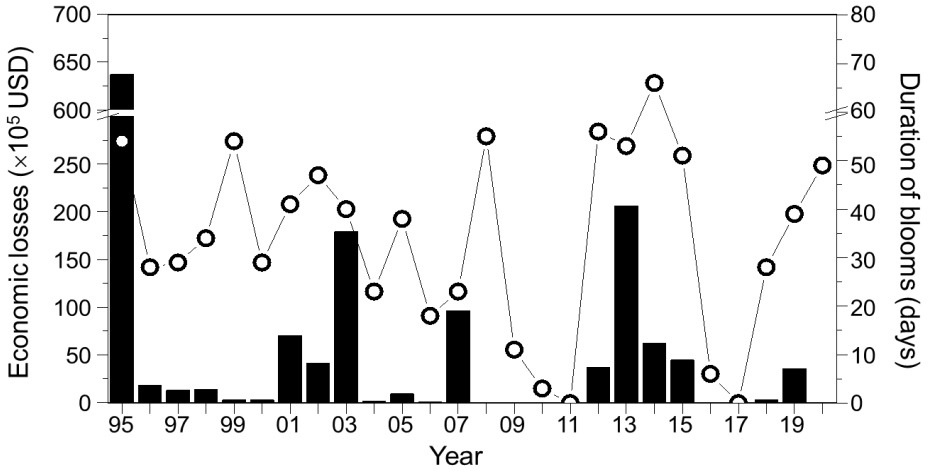
- Long-chain forming: fast swimming
- Occurrence of red tides with high cell densities (> 1000 cells mL^{-1})
- The blooms of *C. polykrikoides* lead the massive mortality of farmed fish and a large economic losses.

Microscope image of *C. polykrikoides* from field samples in 2018.



Microscope video of swimming of *C. polykrikoides* from field samples around southern coast of Korea in 2022.

Photo of aquaculture fish mortality caused by the blooms of *C. polykrikoides* in 2019 (Namhae-gun office)

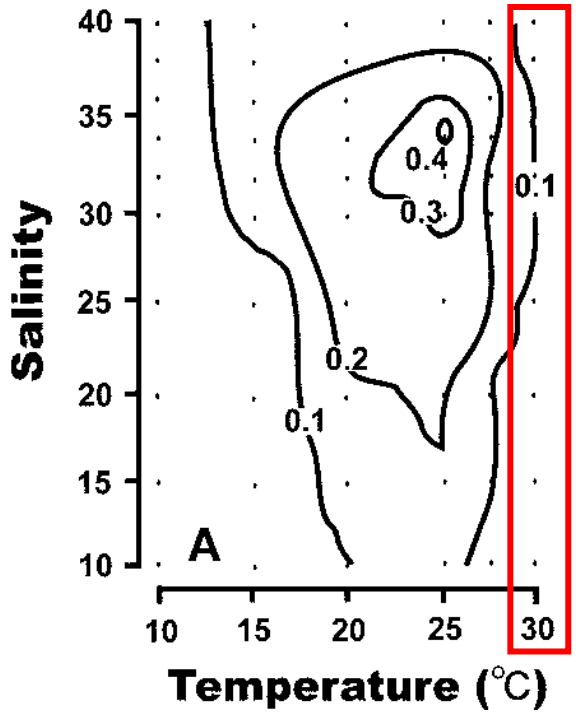


Economics losses caused by *C. polykrikoides* blooms (black bar) and duration of the blooms (circle and line) in Korean coastal waters from 1995 to 2020.

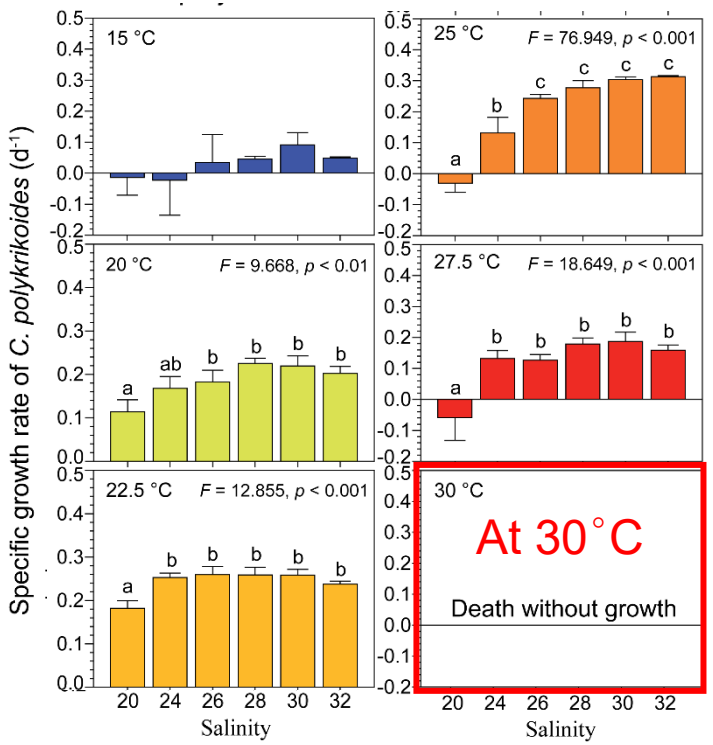
❑ Growth characteristics of *C. polykrikoides* in Korea

- The optimum growth water temperature of *C. polykrikoides* is around 25°C in Korea
- *C. polykrikoides* in Korea cannot grow well at high water temperature reaching 30°C

Around 30˚C



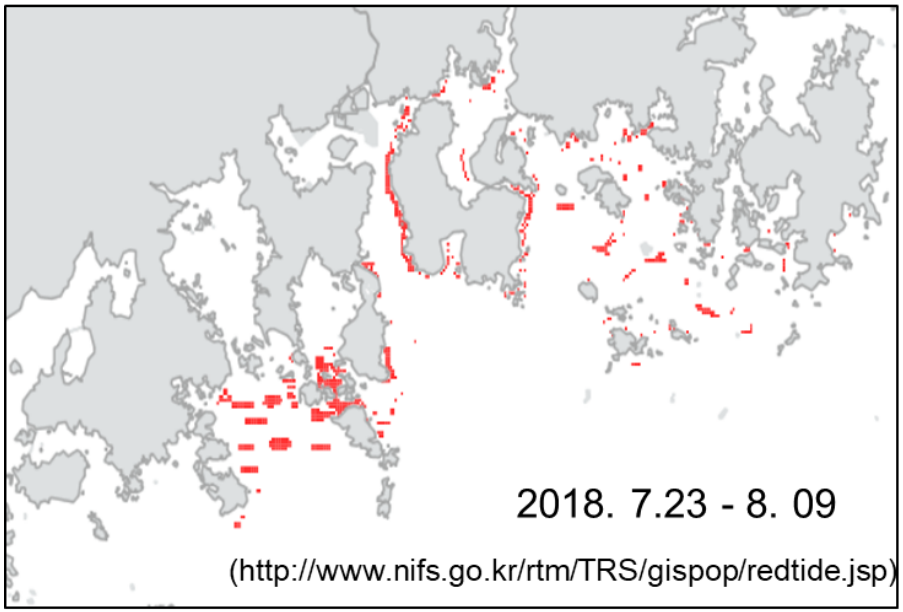
(Kim *et al.*, 2004)



(Lim *et al.*, 2019)

❑ Aim to this study

- **First,** How can the blooms of *C. polykrikoides* occur at extremely high temperatures in Korean coastal waters?
  - Growth experiment & genotype analysis of the strain 2018 in the laboratory
- **Second,** How did MHWs affect the blooms of *C. polykrikoides* in 2018?
  - Bloom dynamics & DVM patterns in the field



Date	WT (°C)
2018-07-24	29.3
2018-07-25	29.1
2018-08-01	30.3
2018-08-02	29.9
2018-08-03	29
2018-08-04	29.6
2018-08-05	29
2018-08-06	30
2018-08-07	29.9
2018-08-08	30.1
2018-08-09	29.8

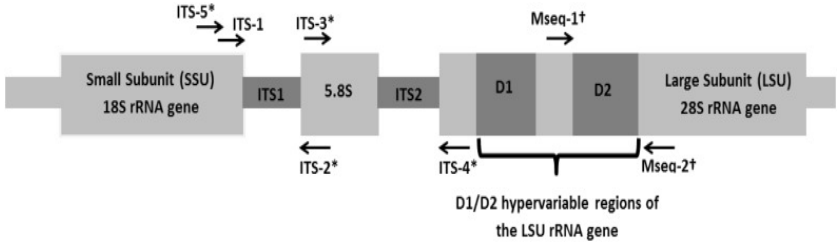
❑ Laboratory experiments-growth characteristics and genotype

- Experimental water temperatures: 25°C, **28°C, 28.5°C, 29°C, 29.5°C, 30°C**
- Culture conditions : Salinity of 32, 100 μmol m^{-2} s^{-1} of irradiance (12L/12D), F/2 media
- Phylogenetic analysis of *C. polykrikoides* (Sequencing of the D1-D2 region of LSU rDNA)
- In both experiments, the *C. polykrikoides* strain in 2013 was used as the reference strain (provided by Library of Marine Samples of KIOST; Incubating at 25°C)

< Incubation >

< microscope >

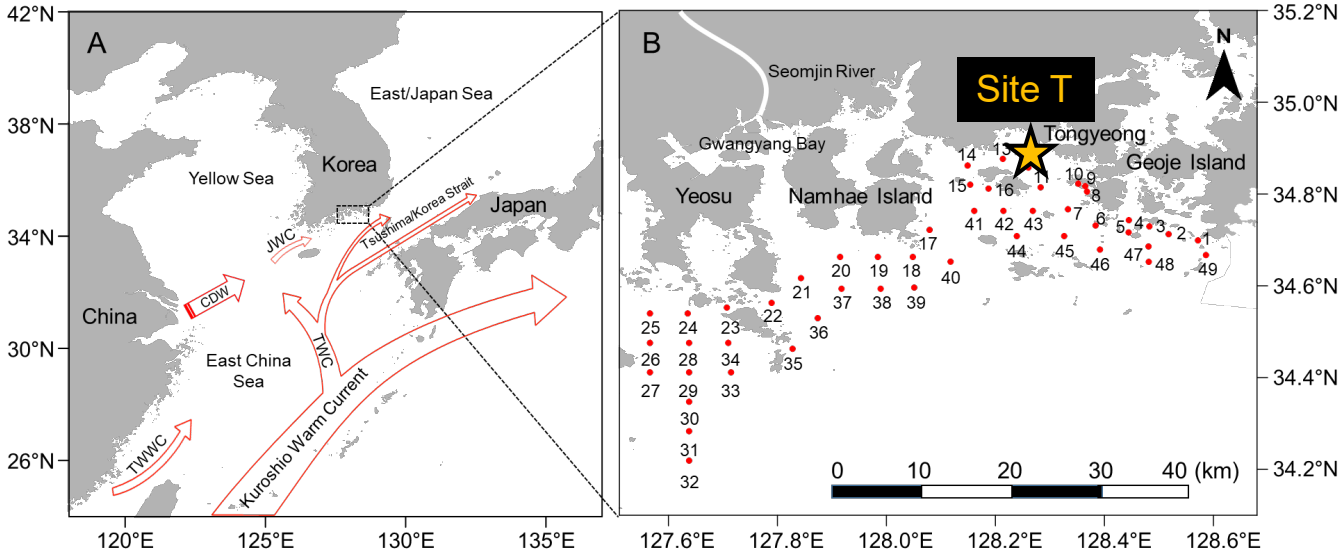
Arbefeville et al., (2017)



< Sequencing region >

❑ Field survey-bloom dynamics and DVM

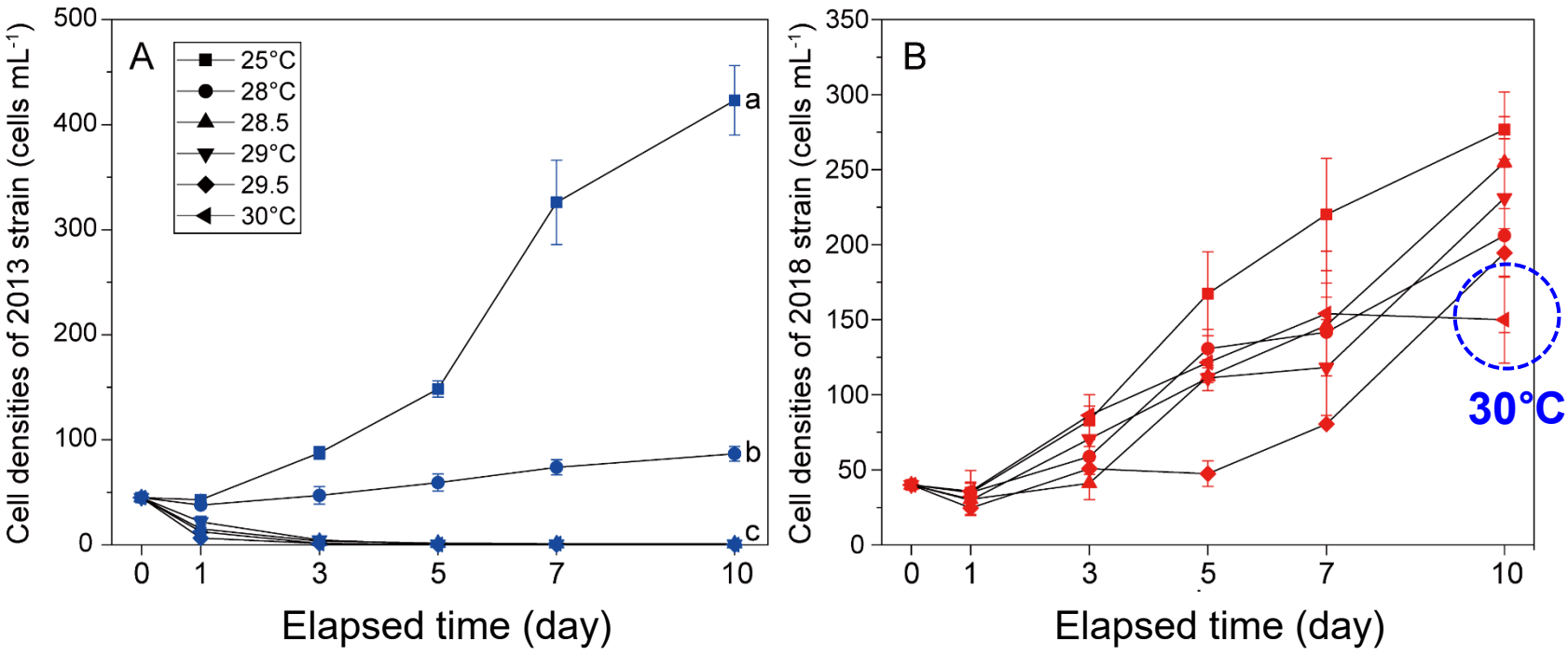
- Horizontal surveys at 49 stations were conducted biweekly from 25th June to 20th August around Geoje island ~ Yeosu
- In-situ vertical investigation was performed at Site T ★ for 48 hours at 1-2 intervals from 8 to 10 August
- The field investigations focused on the changes of *C. polykrikoides* and environmental factors (temperature, salinity, nutrients)



❑ Different growth characteristics of both *C. polykrikoides*

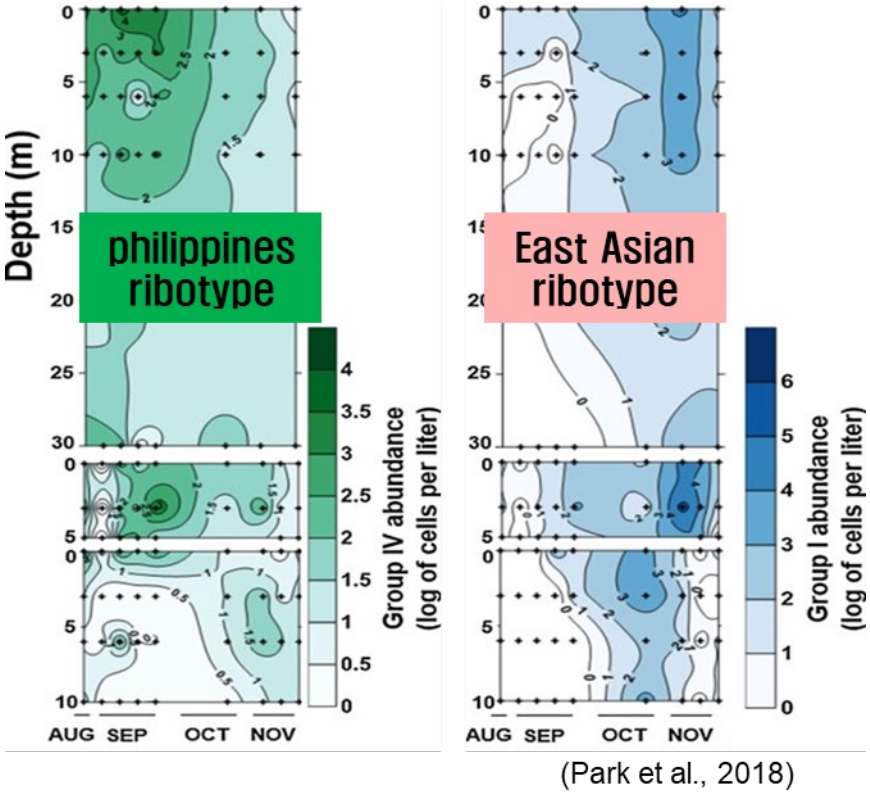
- The response to high temperatures was very different for two strains.
- Only the 2018 strain grew in high WT (> 28°C)
- The growth rate was relatively low at 30°C: **potential stress for growth**

The strain 2013 | **The strain 2018 from MHWs**

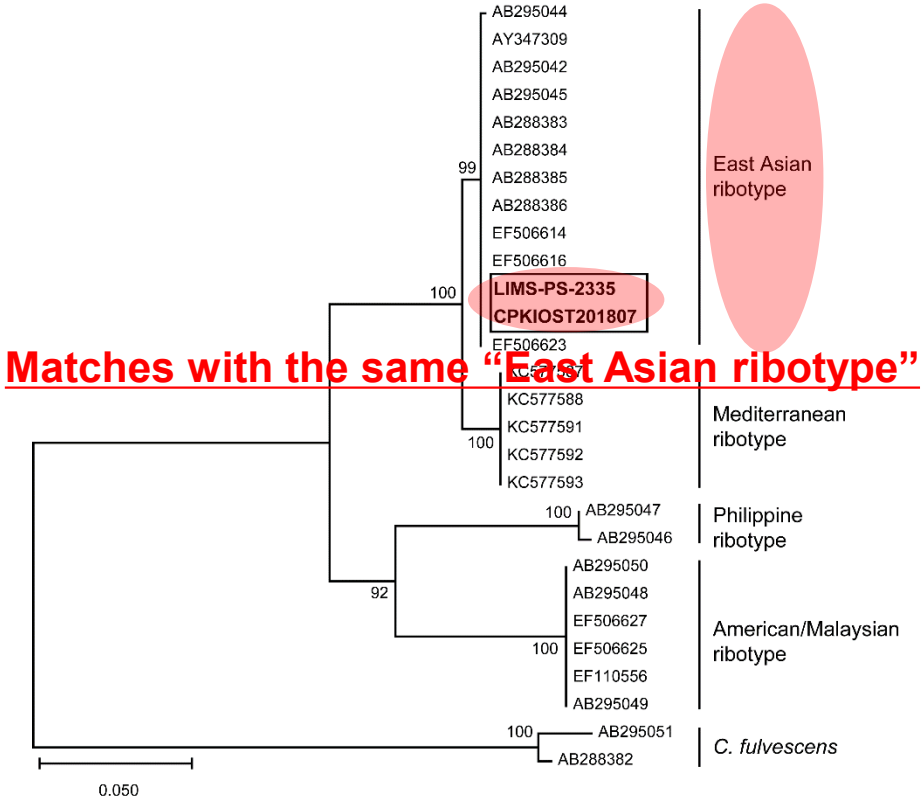


❑ Phenotype plasticity of *C. polykrikoides*

- According to previous studies, *C. polykrikoides* is separated into four ribotypes
- In Philippine, blooms of *C. polykrikoides* occurred above 30°C (Azanza et al., 2008)
- Both the strains in 2013 and 2018 were positioned at the “East Asian ribotype”
- ***C. polykrikoides* has phenotype plasticity even with the same genotype**



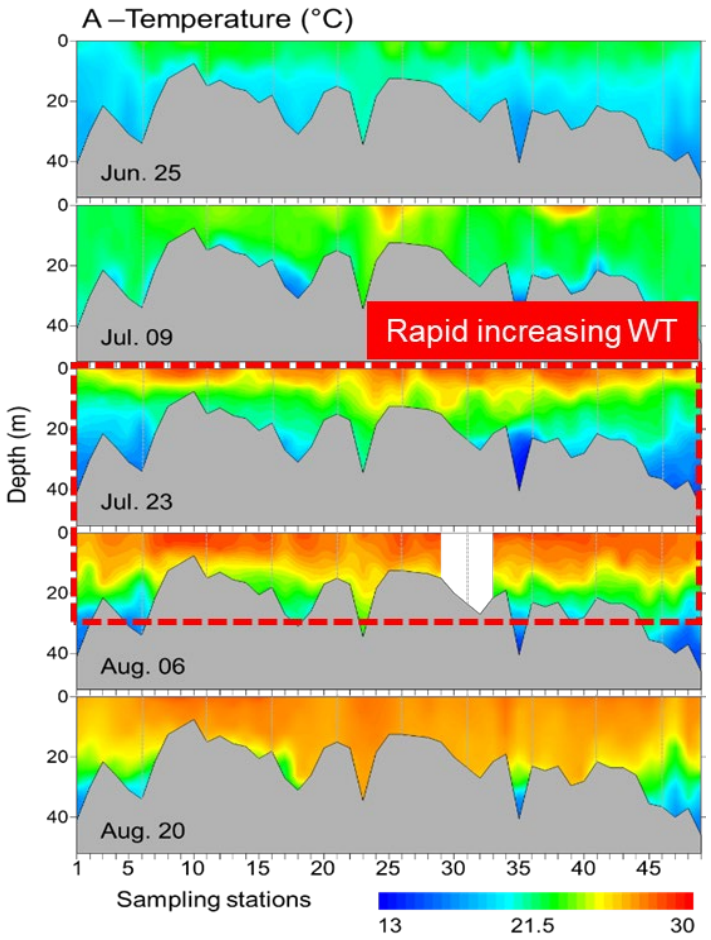
(Park et al., 2018)



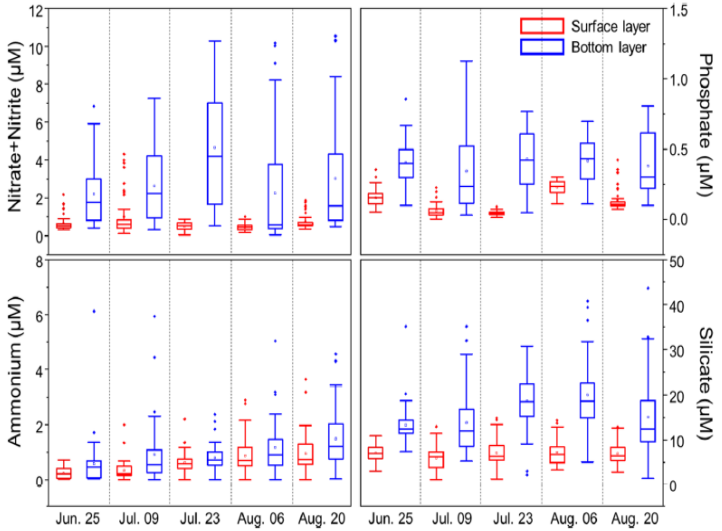
Matches with the same “East Asian ribotype”

❑ Rapid warming and stratification

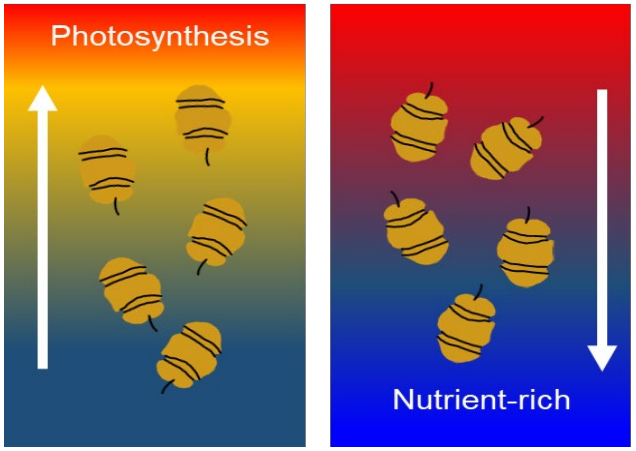
- MHWs developed a strong stratification and depleted the surface nutrients: benefit for DVM organisms, including *C. polykrikoides*



Nutrient depletion in surface layer

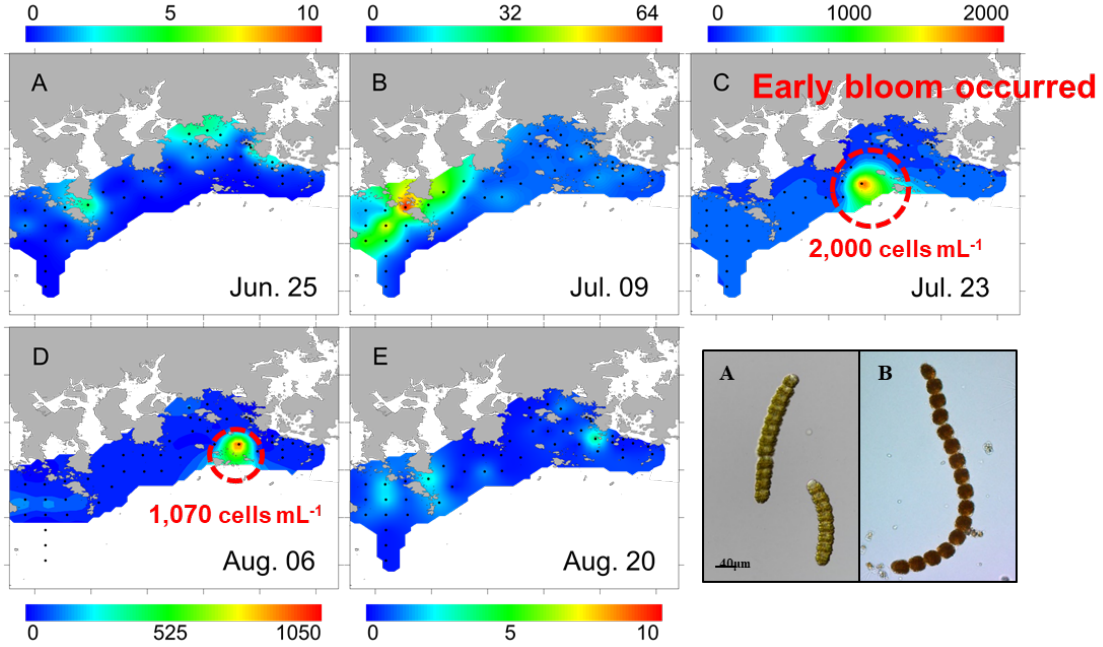


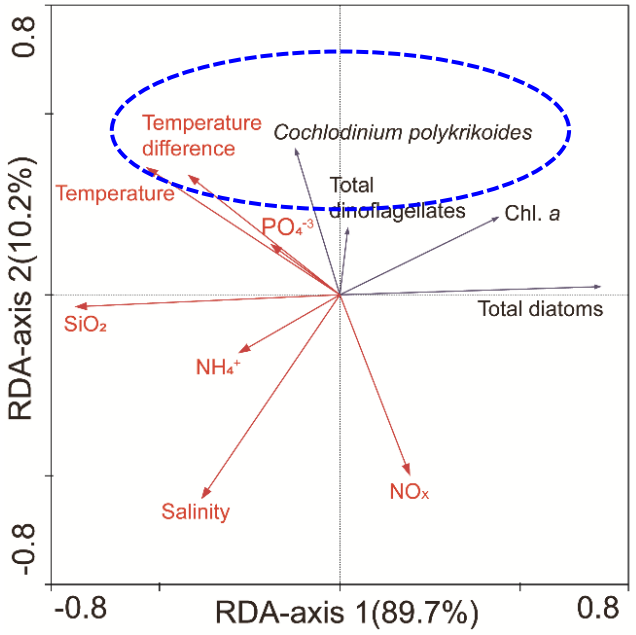
Benefit for DVM organisms



❑ Rapid warming and stratification in 2018

- Early stratification → early bloom in 2018 (NIFS; average of last 17 years : 10th Aug.)
- Temperature difference between surface and bottom water positively correlated with the abundance of *C. polykrikoides*





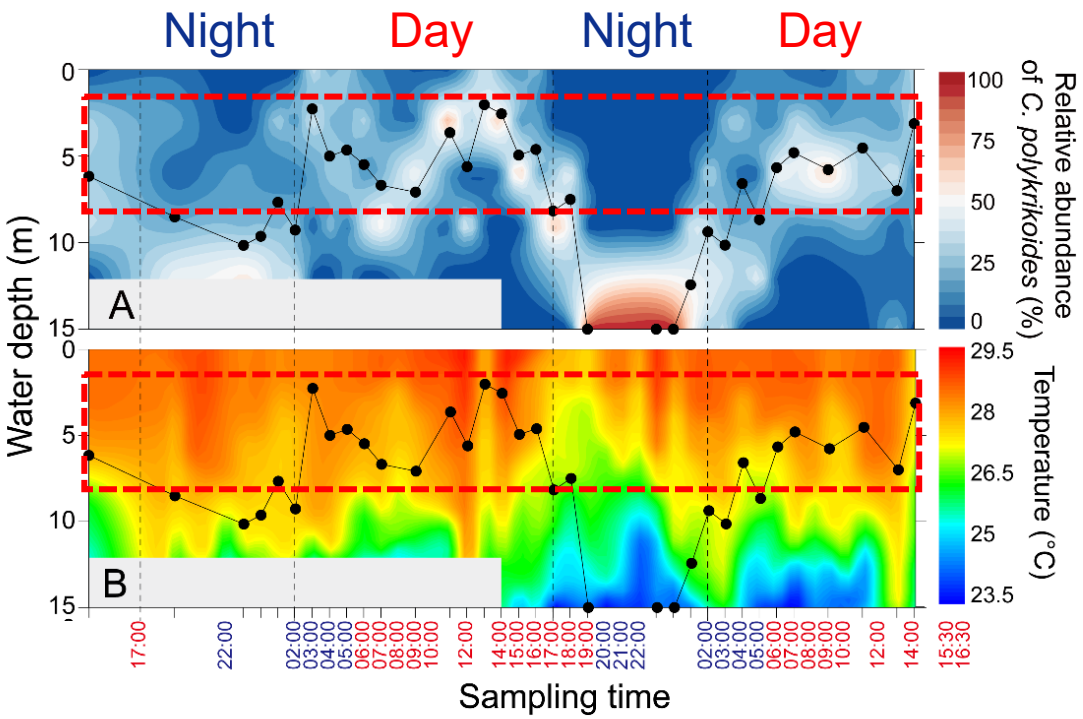
Horizontal distribution of *C. polykrikoides*e (cells mL^{-1})

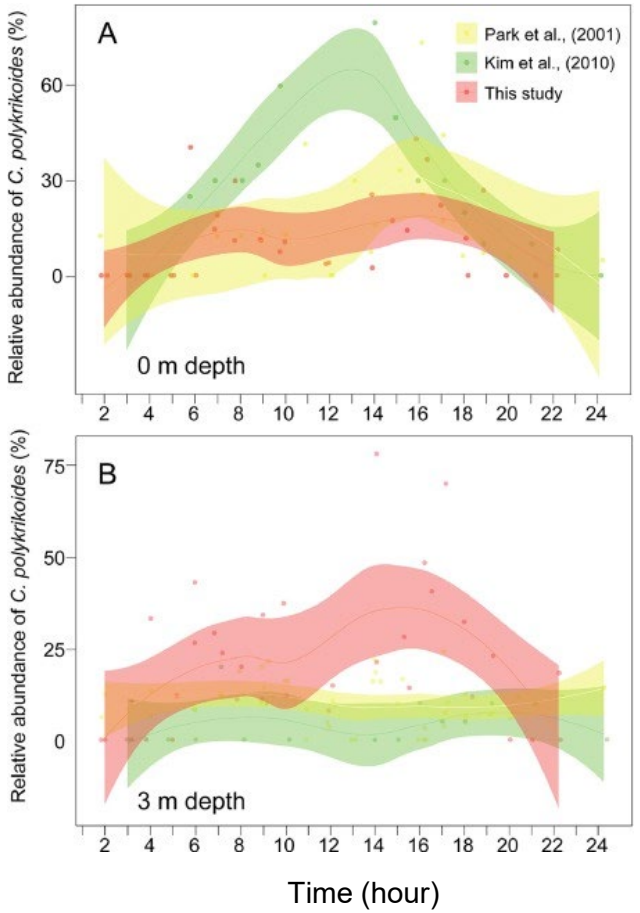
Positive effect of MHWs on bloom formation !

So, does the rise in water temperature only have a positive effect?

❑ Vertical distribution of *C. polykrikoides* during MHWs

- During MHWs in 2018, most of *C. polykrikoides* did not reached at 0 m depth during daytime
- Normal blooms at 25°C in previous studies: most of *C. polykrikoides* were distributed at 0 m during daytime
- These results suggested that the limited DVM behavior in 2018

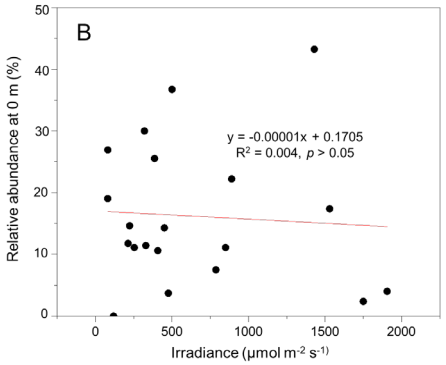


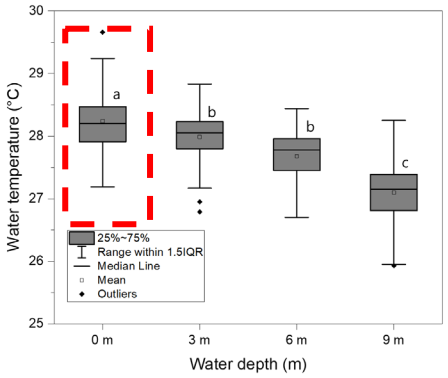


❑ Thermotaxic DVM of *C. polykrikoides*

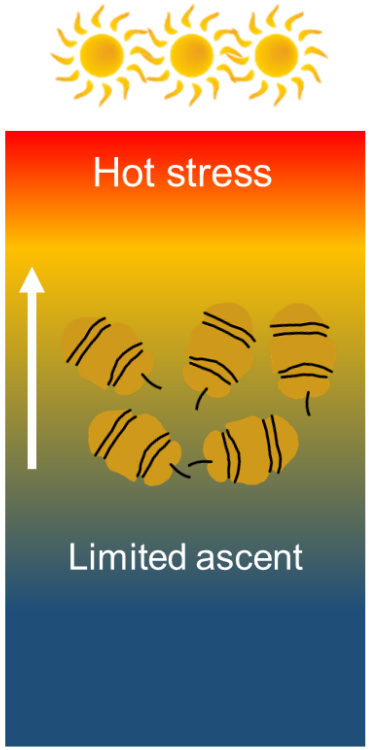
- There is no significant correlation between *C. polykrikoides* and irradiance ($p > 0.05$, Mann-Whitney U-test)
- Water temperature at 0 m was significantly higher than that of 3-6 m depths ($p < 0.05$, Kruskal-Wallis test)
- Some dinoflagellates exhibited “thermotaxic behavior” (Clegg et al., 2003)
- Potential decrease of suitable habitat and of photosynthesis efficiency

Non-correlation with irradiance





High temperature at 0 m



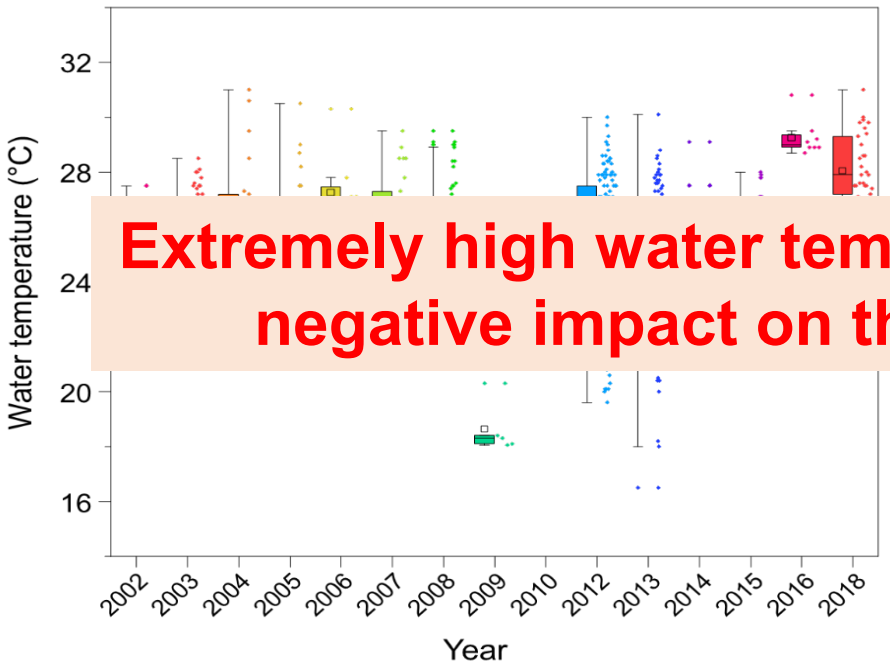
Limited DVM behavior

MHWs cause thermal stress

To overcome, do limited DVM by thermotaxis as ecological strategy

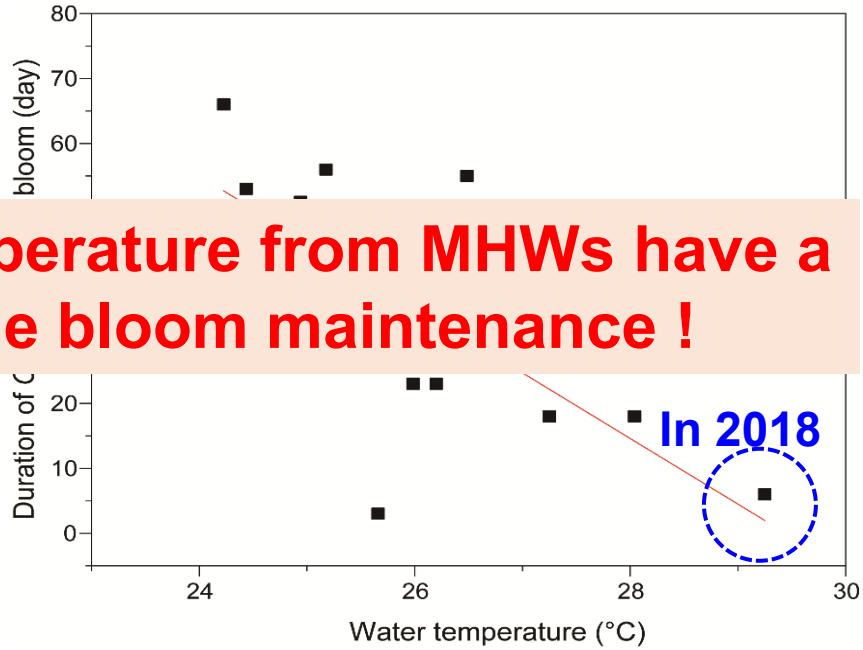
❑ Relationship between WT and *C. polykrikoides* bloom

- Most of *C. polykrikoides* blooms have occurred between 24-27°C during last 17 years
- The blooming period in 2018 was unusually shorter than in the past 17 years, despite an ecological strategy of thermotaxic DVM
- Negative correlation between WT and bloom duration, indicating that high WT is unfavorable for the bloom of *C. polykrikoides* in Korea



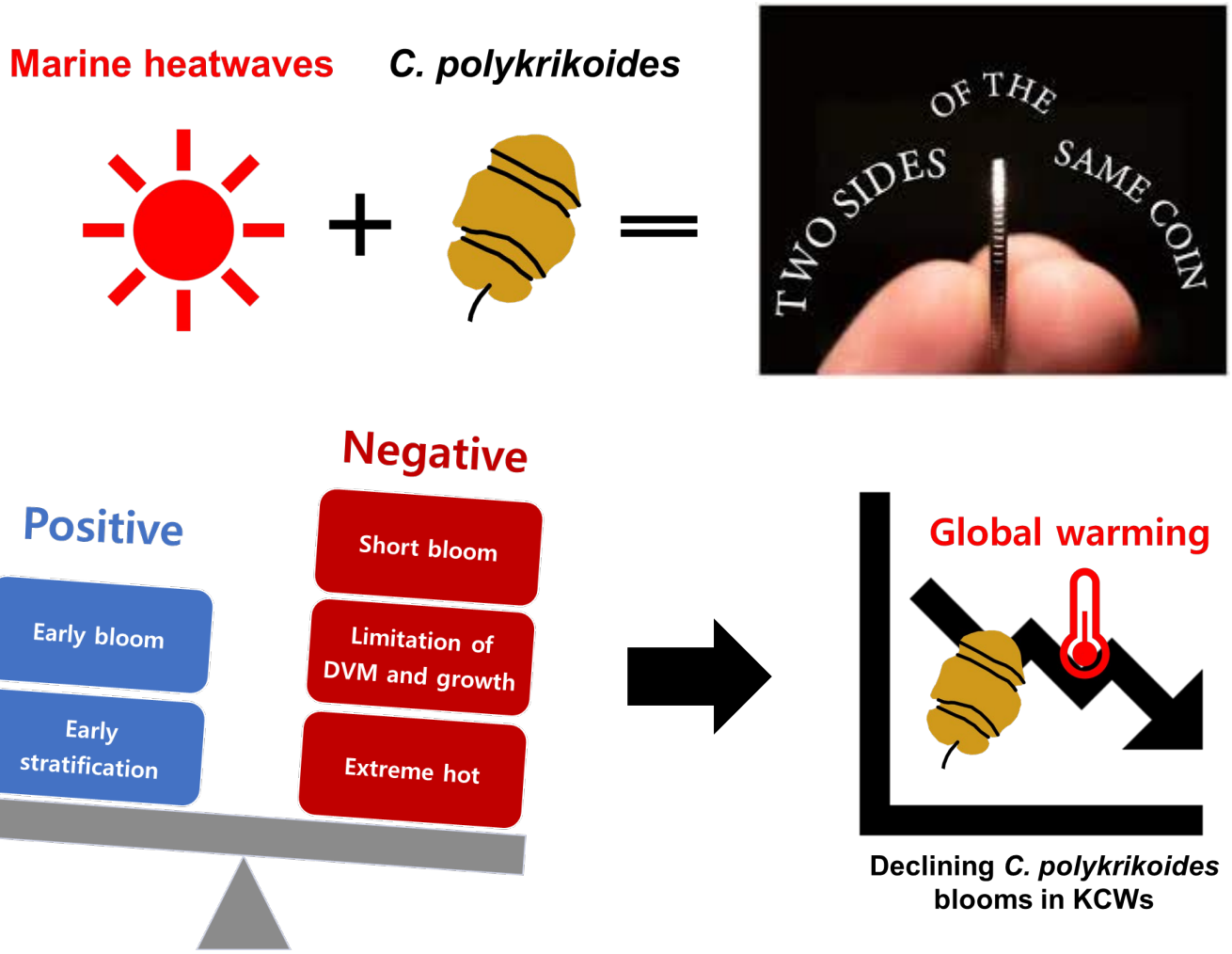
<Variations in water temperature during *C. polykrikoides* blooms from 2002 to 2018.>

Extremely high water temperature from MHWs have a negative impact on the bloom maintenance !



<Relationship between average water temperature and duration in each *C. polykrikoides* blooming year from 2002 to 2018>

Conclusion



✓ **The strengthening MHWs with global warming is likely to negatively affect *C. polykrikoides* blooms in the future !**

Publications

Harmful Algae 104 (2021) 102029

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Effect of marine heatwaves on bloom formation of the harmful dinoflagellate *Cochlodinium polykrikoides*: Two sides of the same coin?

Young Kyun Lim [a,b], Bum Soo Park [c], Jin Ho Kim [a,d], Sang-Soo Baek [e], Seung Ho Baek [a,b,*]

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Thermotaxic diel vertical migration of the harmful dinoflagellate *Cochlodinium* (*Margalefidinium*) *polykrikoides*: Combined field and laboratory studies

Young Kyun Lim [a,b], Jin Ho Kim [a,c], Hyejoo Ro [a], Seung Ho Baek [a,b,*]

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