Heavy precipitation-induced Yangtze River runoff greatly regulates HPP and induces P-limited growth in the northern East China Sea

*HPP – heterotrophic prokaryotes production

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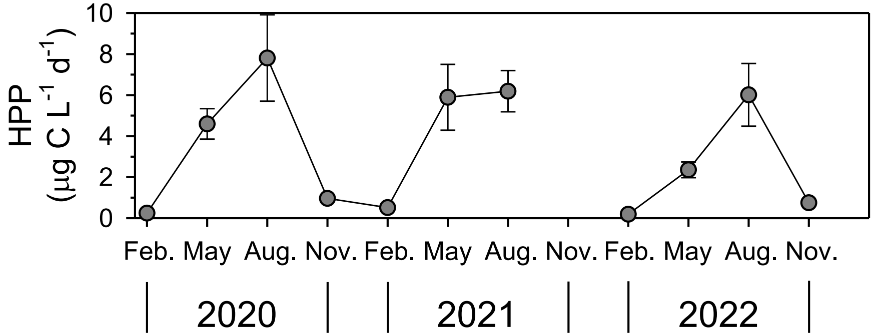
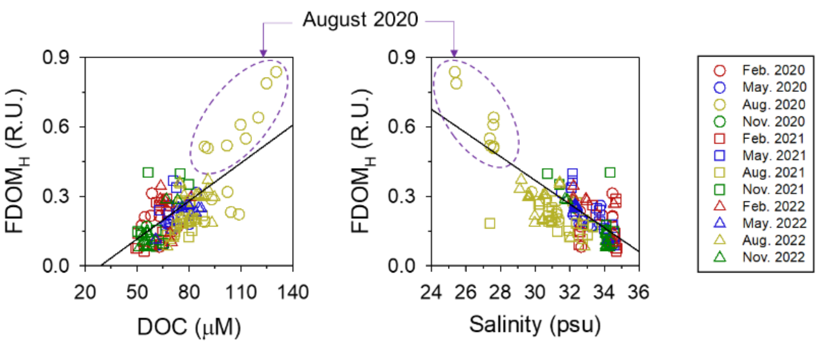
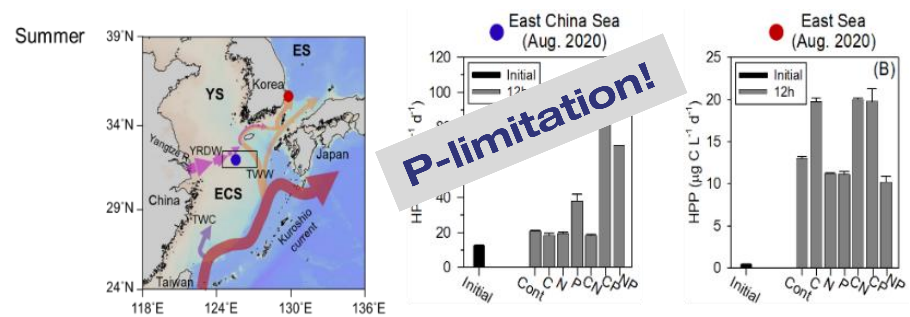
Highlights of this study

***YRDW - Yangtze River diluted water *HPP – Heterotrophic prokaryotes production**

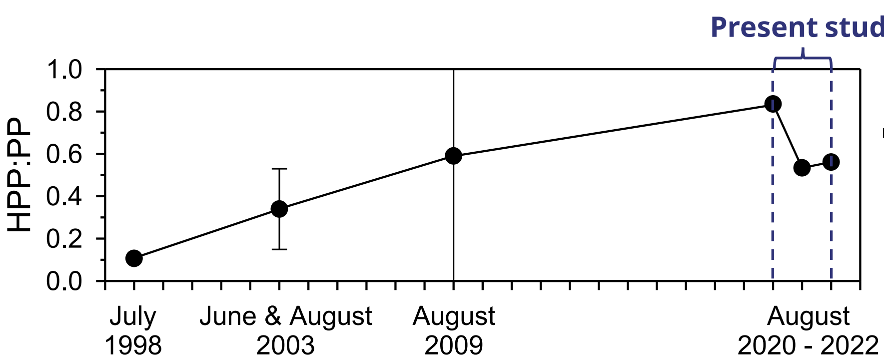


- **YRDW enhances summer heterotrophic prokaryotes production (HPP) in the northern East China Sea (nECS) by supplying DOC and stimulating primary production.**





- **Excessive YRDW input suppresses HPP by reducing DOC bioavailability and causing nutrient imbalance.**



- **Over the past two decades, microbial food web has been strengthened, potentially altering fishery production and ecosystem structure**

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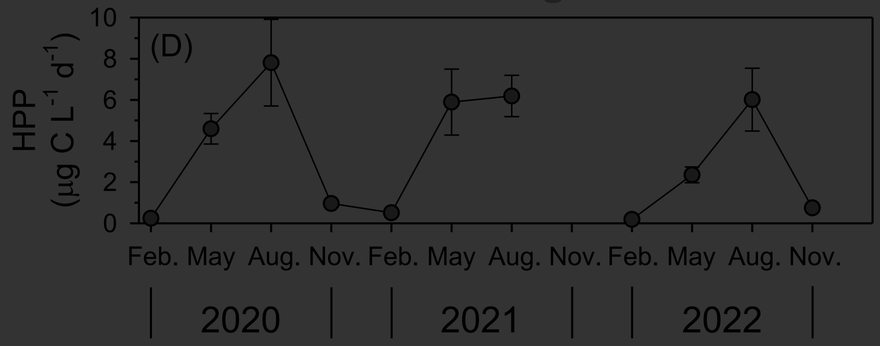

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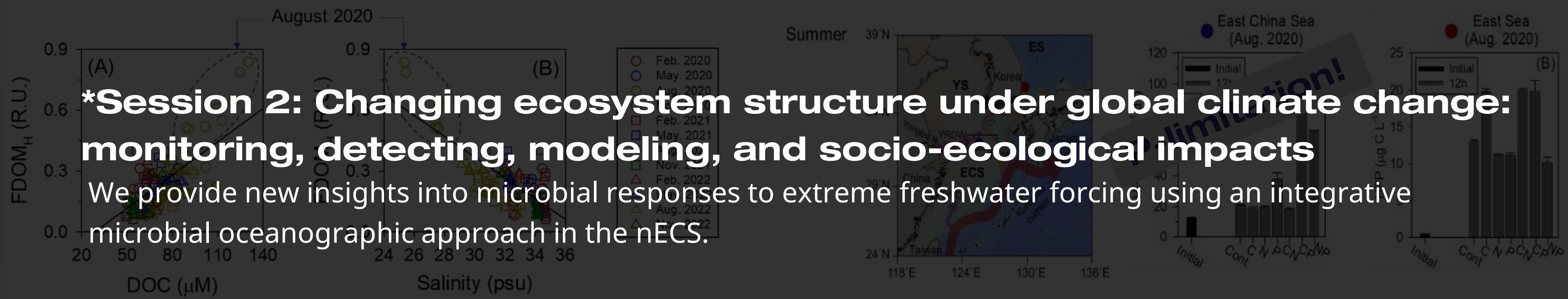
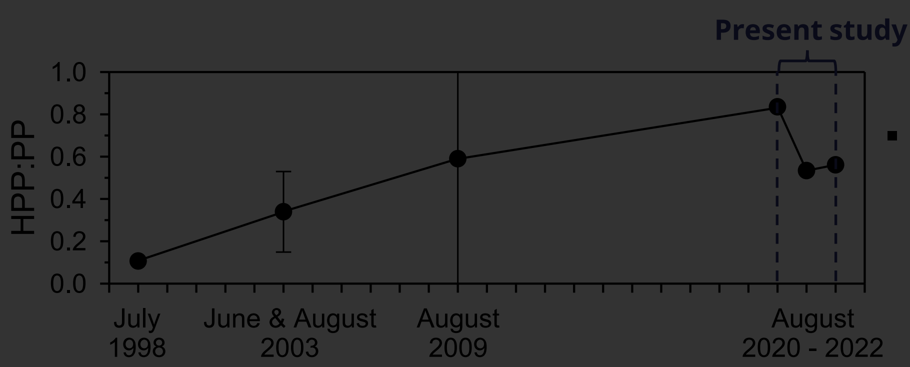


***Session 2: Changing ecosystem structure under global climate change: monitoring, detecting, modeling, and socio-ecological impacts**

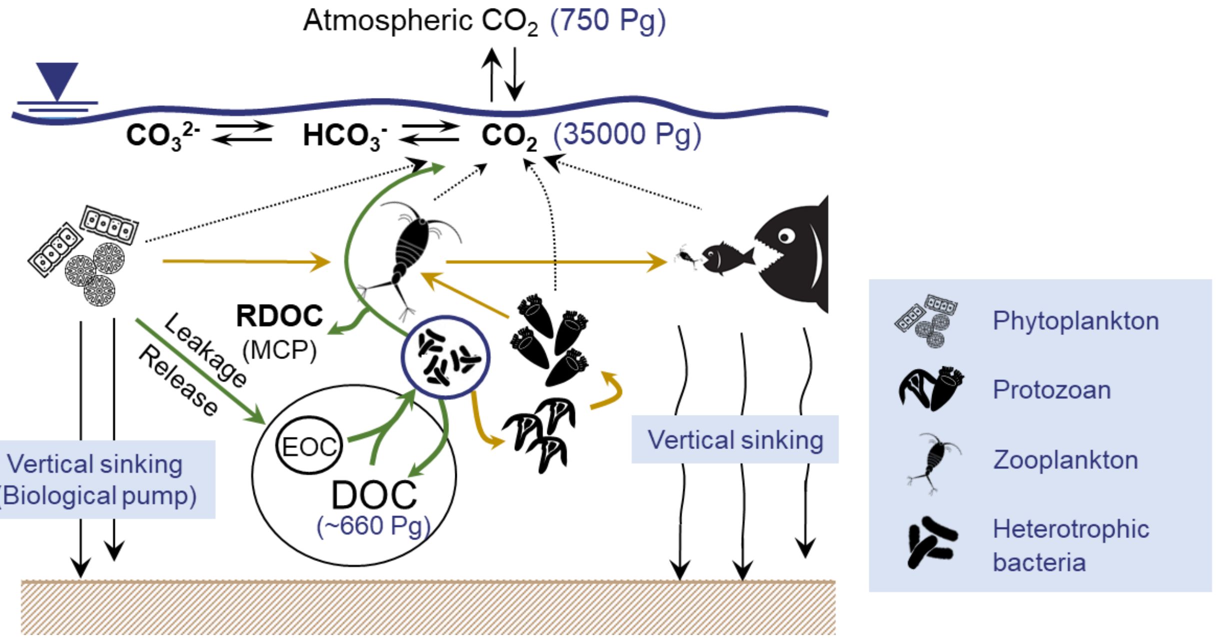
We provide new insights into microbial responses to extreme freshwater forcing using an integrative microbial oceanographic approach in the nECS.

- **Excessive YRDW input suppresses HPP by reducing DOC bioavailability and causing nutrient imbalance.**



- **Over the past two decades, microbial food web has been strengthened, potentially altering fishery production and ecosystem structure**

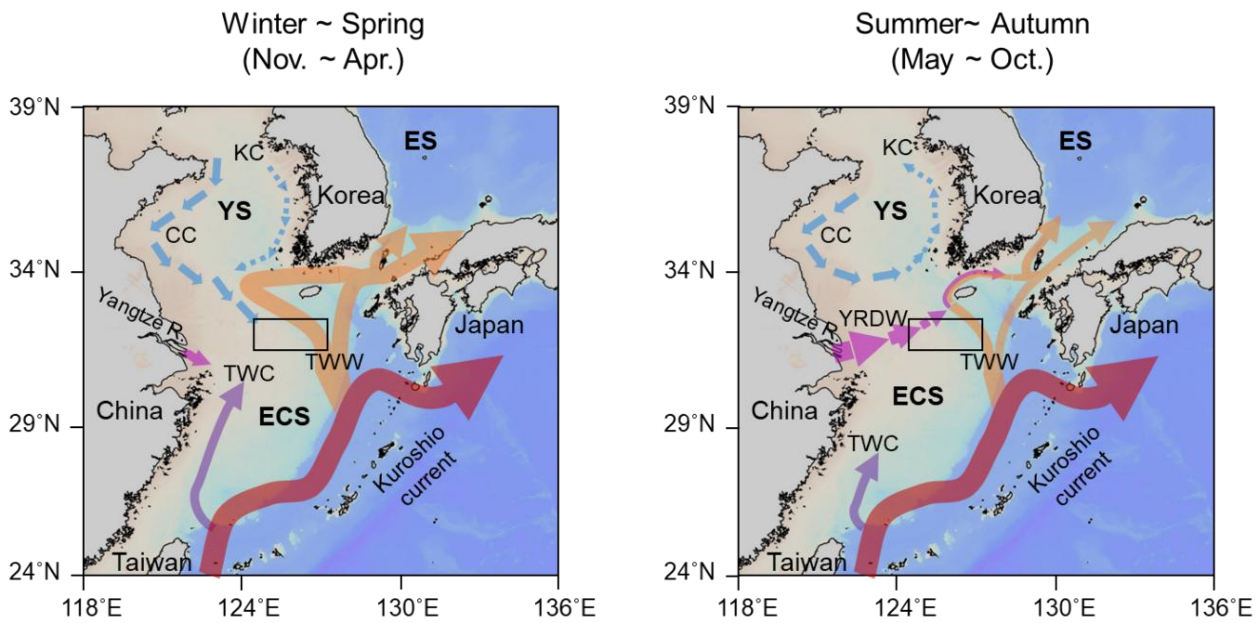
Background I Heterotrophic prokaryotes in microbial oceanography



Pathways of carbon processing and transfer by heterotrophic prokaryotes in the ocean.

- **Large oceanic DOC pool**
  - DOC in the ocean is comparable in size to atmospheric CO_2.
  - It includes a wide range of reactive and refractory compounds.
- **Heterotrophic prokaryotes (HP) control DOC fate through:**
  ⓐ Trophic transfer (microbial loop)
  ⓑ Respiration (DOC → CO_2)
  ⓒ Carbon sequestration (via microbial carbon pump)
- **Quantifying HP is essential in microbial oceanography**
  - HP biomass, production, and respiration
  - Understanding their controlling factors
  → **Key to biogeochemical carbon cycling**

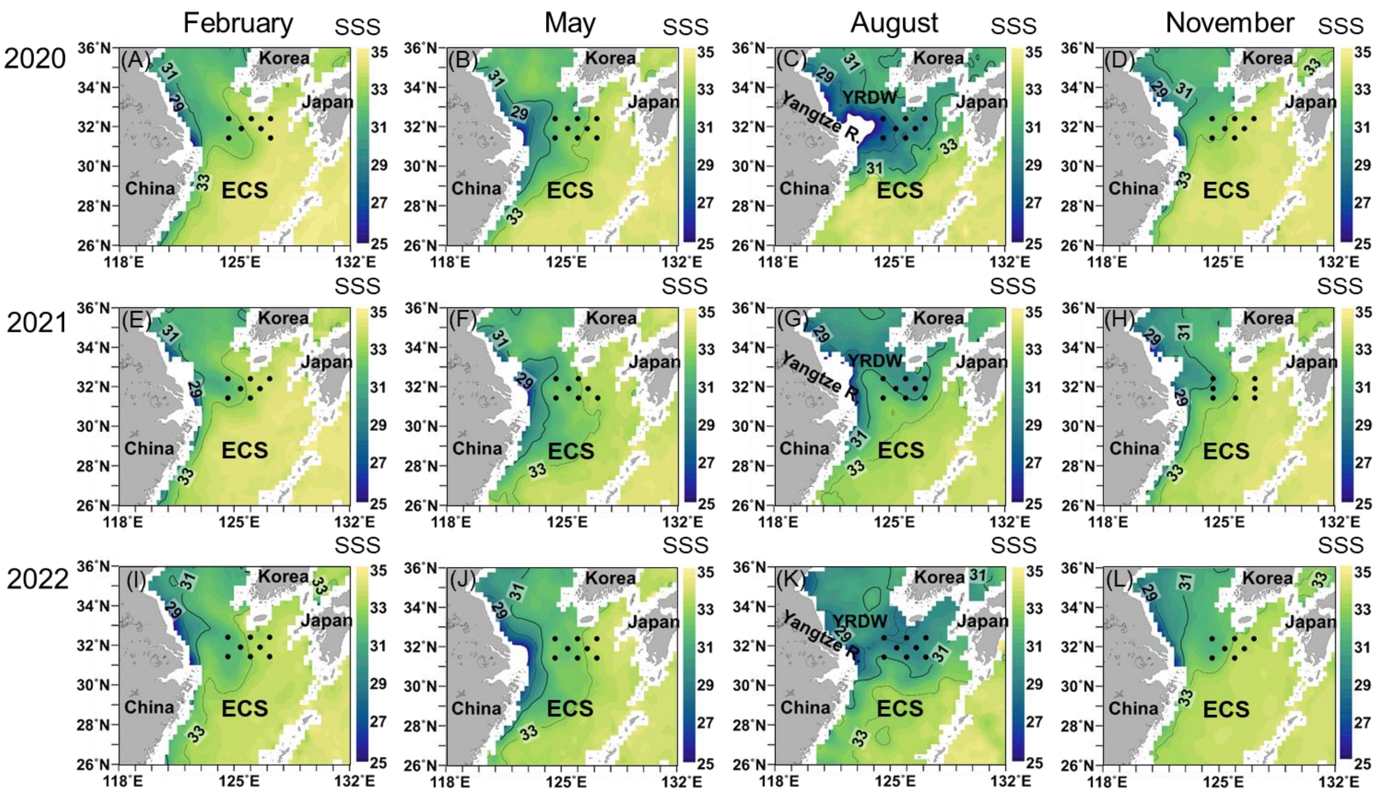
Background | Yangtze River influence on the East China Sea ecosystem



Seasonal surface currents of the Northwest Pacific Ocean. YS: Yellow Sea, ECS: East China Sea, ES: East Sea, CC: China coastal current, KC: Korean coastal current, YRDW: Yangtze River diluted water, TWC: Taiwan warm current, TWW: Tsushima warm water.

- **East China Sea (ECS): a dynamic shelf system**
  - Largest continental shelf in the NW Pacific (1.25 x 10^6 km^2).
  - Major carbon sink (2.0 – 3.0 mol C m^{-2} yr^{-1}, Wang et al. 2000).
- **Yangtze River diluted water (YRDW): a dominant summer-time driver**
  - The Yangtze River discharges ~26,400 m^3 s^{-1} (Mei et al. 2015).
  - Summer YRDW delivers substantial amounts of DOC (1.85 Tg C yr^{-1}), nitrogen (1.69 Tg N yr^{-1}), and phosphorus (0.11 Tg P yr^{-1}) with a potentially imbalanced N:P ratio.
- **Ecological implications**
  - ECS is rapidly changing due to climate-driven warming and extreme rainfall
  - High runoff raises critical questions about HP growth and microbial responses

Background | Study site: northern East China Sea



Satellite images of sea surface salinity (SSS) during sampling periods (2020–2022)

- **Study site**
  - Northern ECS: a key passage for DOC and nutrients from the Yangtze River and southern China Sea
  - Seasonally sampled 7–8 stations (2020–2022)

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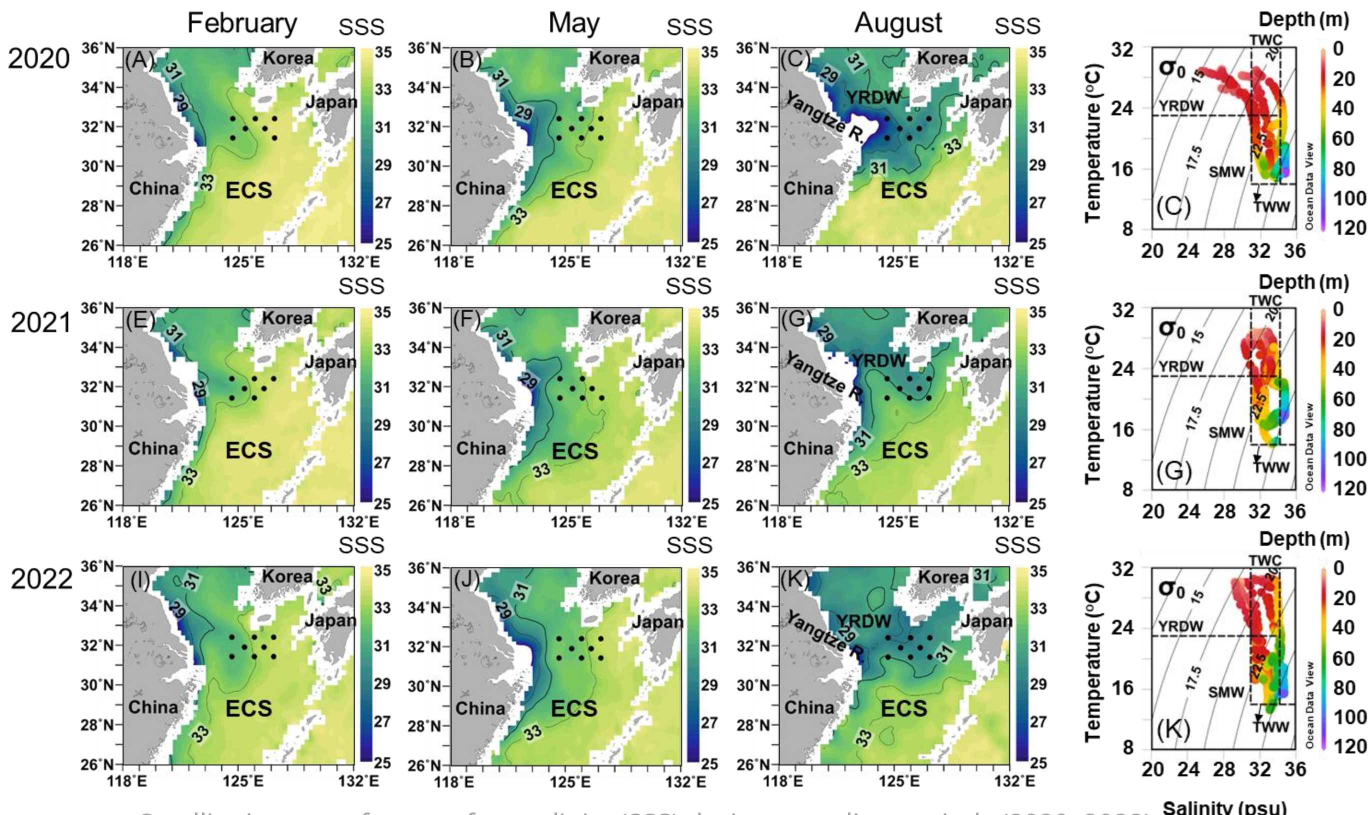


Satellite images of sea surface salinity (SSS) during sampling periods (2020–2022)

- **Study site**
  - Northern ECS: a key passage for DOC and nutrients from the Yangtze River and southern China Sea
  - Seasonally sampled 7–8 stations (2020–2022)
- **YRDW inflow and spread**
  - Satellite SSS maps and T–S diagrams show strong YRDW expansion in August
  - Strongest intrusion in August 2020, followed by 2022 and 2021
- **Objective**
  - To understand how YRDW strength regulates heterotrophic prokaryote production and associated carbon cycling, under increasingly frequent and intense rainfall in East Asian marginal seas.

Materials & methods I Environmental and microbial parameters

Physical parameters

- Temperature & Salinity : SBE 911; Seabird Electronics, USA

Chemical parameters

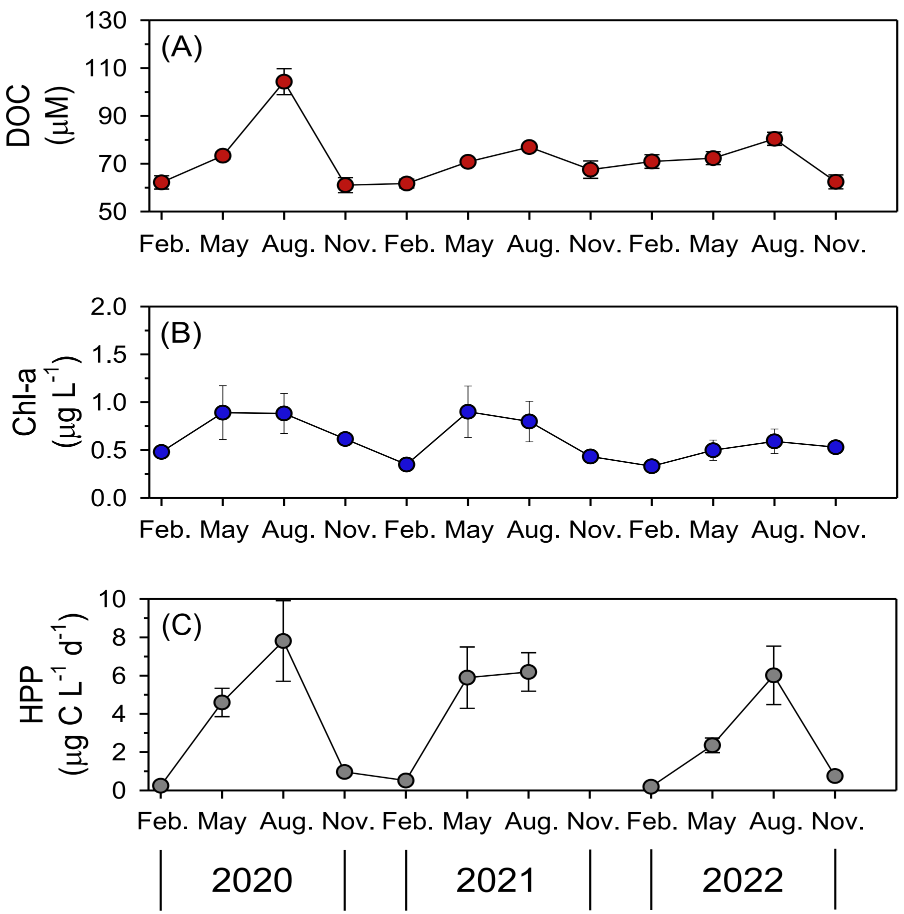
- Dissolved inorganic nitrogen (DIN; NO_2^-+NO_3^-) & Dissolved inorganic phosphate (DIP) : continuous Auto-Analyzer (Quaatro; Seal Analytical, Norderstedt, Germany)
- Dissolved organic carbon (DOC) : High-temperature catalytic oxidation method (TOC-L; Shimadzu, Japan)
- Chlorophyll-a (Chl-a) : Spectrophotometric method (Tuner Designs 10-Au; San Jose, CA, UAS)
- Fluorescent dissolved organic matter (FDOM) : Excitation-emission matrix spectroscopy (EEMS) analysis (Hitachi F-7100, Tokyo, Japan) with Parallel factor analysis (PARAFAC)

Microbial parameters

- Primary production (PP) : uptake of $NaH^{13}CO_3$ method (Hama et al., 1983)
- Heterotrophic prokaryotes production (HPP) : ^{3}H-Leucine incorporation method (Smith and Azam, 1992)

Key Result 1 | Stimulation of summer HPP by DOC and phytoplankton fertilization from YRDW

***YRDW** - Yangtze River diluted water ***HPP** – Heterotrophic prokaryotes production



- **HPP, DOC, and Chl-a consistently peaked in August, indicating a strong association with the summer expansion of YRDW.**

Seasonal variations of (A) DOC concentrations (averaged over the mixed layer), (B) Chl-a concentrations (averaged within the euphotic zone), and (C) HPP (averaged over the mixed layer) in the northern East China Sea. Error bars indicate standard errors.

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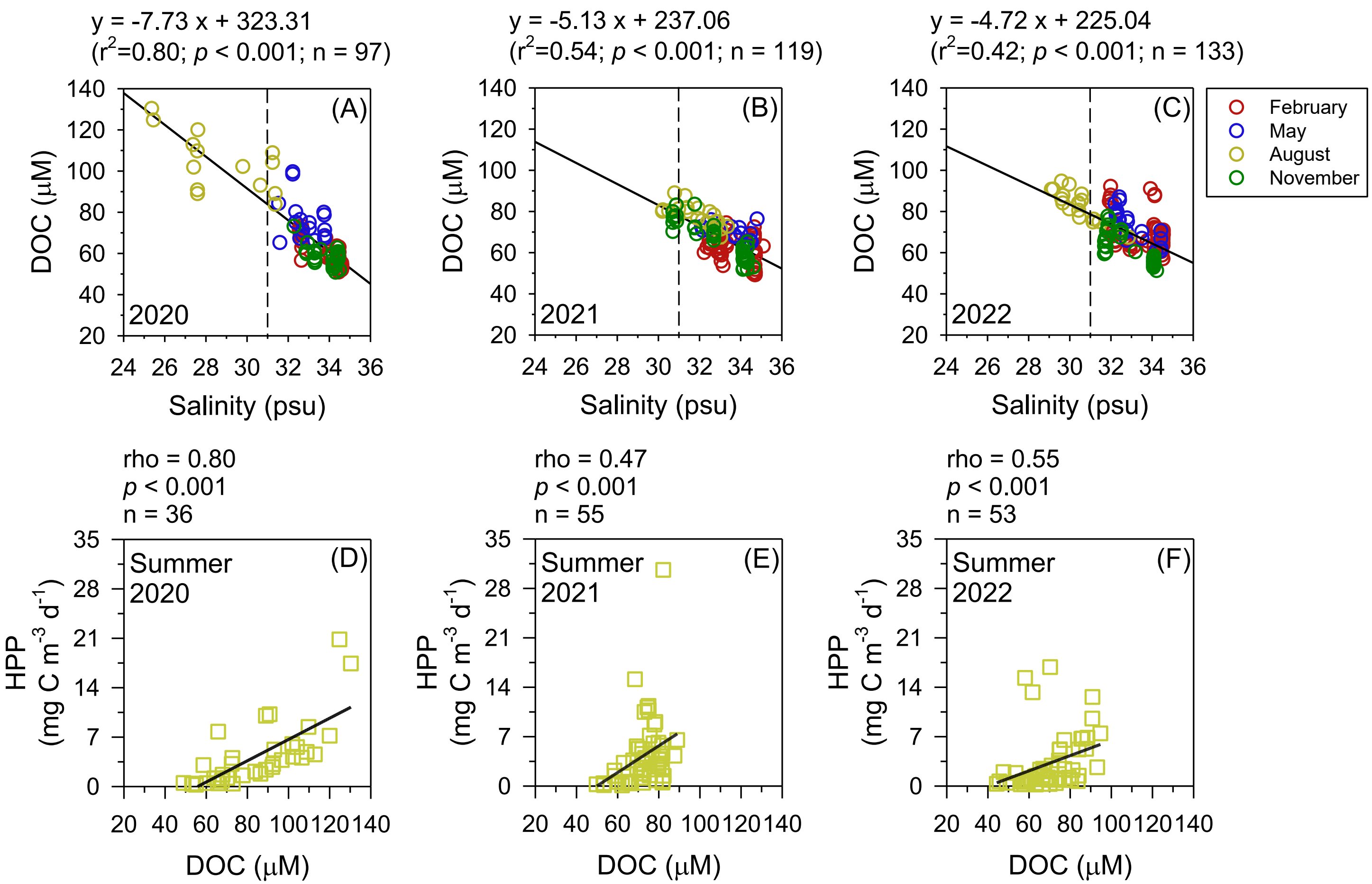

Relationship between salinity and DOC (A, B, and C) within mixed layer depth in 2020, 2021, and 2022, and between DOC and HPP (D, E, and F) during summers of 2020, 2021 and 2022 in the nECS.

- **Low salinity waters in August suggest DOC input via YRDW.**
- **DOC positively correlated with HPP in summer across three years.**

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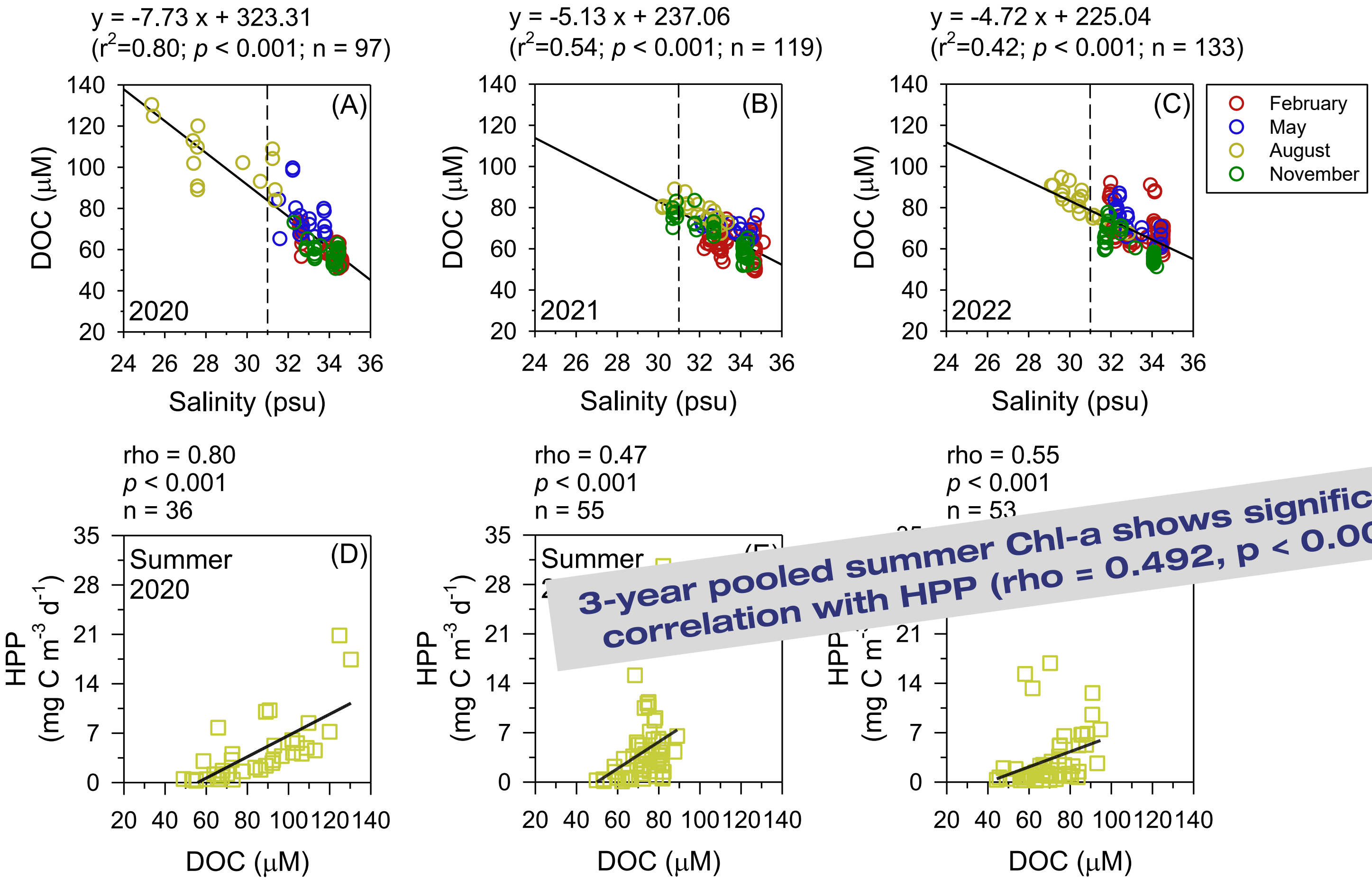


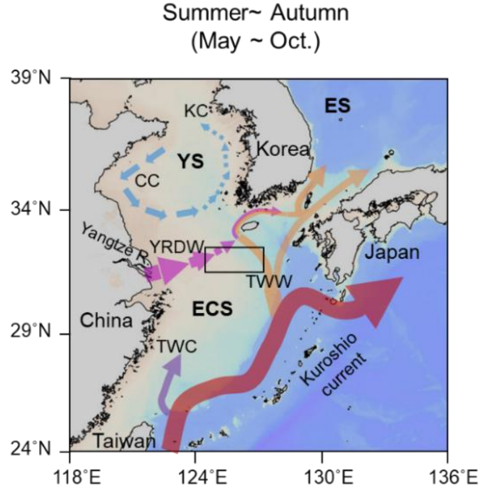
3-year pooled summer Chl-a shows significant correlation with HPP (rho = 0.492, p < 0.001)

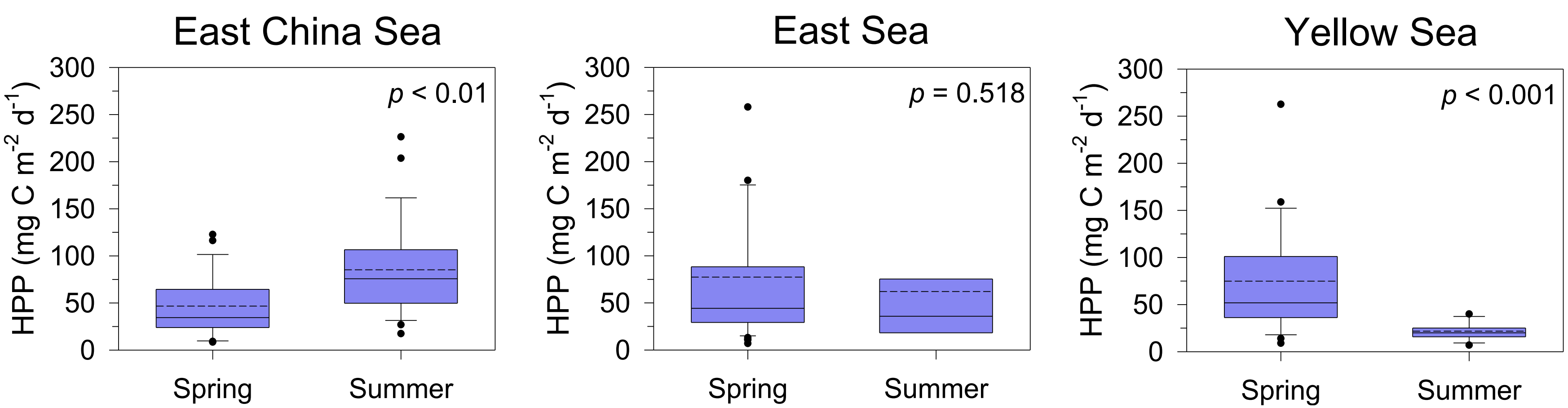
Relationship between salinity and DOC (A, B, and C) within mixed layer depth in 2020, 2021, and 2022, and between DOC and HPP (D, E, and F) during summers of 2020, 2021 and 2022 in the nECS.

- **Low salinity waters in August suggest DOC input via YRDW.**
- **DOC positively correlated with HPP in summer across three years.**
- **YRDW also likely enhanced HPP via phytoplankton-derived OM.**

Key Result 1 | Broader implications of summer HPP increase and YRDW spread into adjacent seas

***YRDW** - Yangtze River diluted water ***HPP** – Heterotrophic prokaryotes production





Comparison of integrated HPP within the mixed layer depth in the East China Sea, the East Sea and the Yellow Sea during spring and summer seasons from 1996 to 2022 (Hyun and Kim, 2003; Hyun et al., 2009; Kim et al., 2017, 2020, 2025; Hyun J-H unpublished data).

- **Summer HPP in East Sea remained high due to YRDW input ($p = 0.518$), while Yellow Sea showed a significant seasonal difference ($p < 0.001$).**

Key Result 2 | Excessive YRDW input altered DOC bioavailability and limited HPP stimulation

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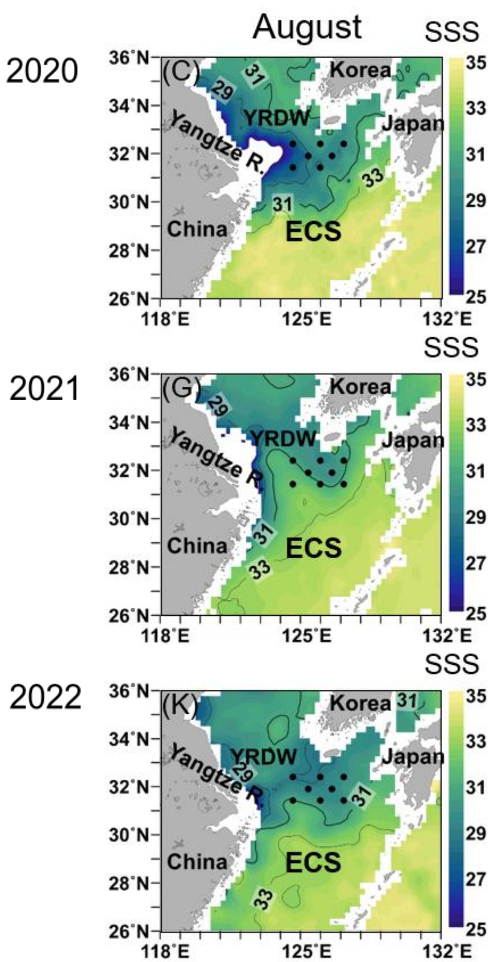

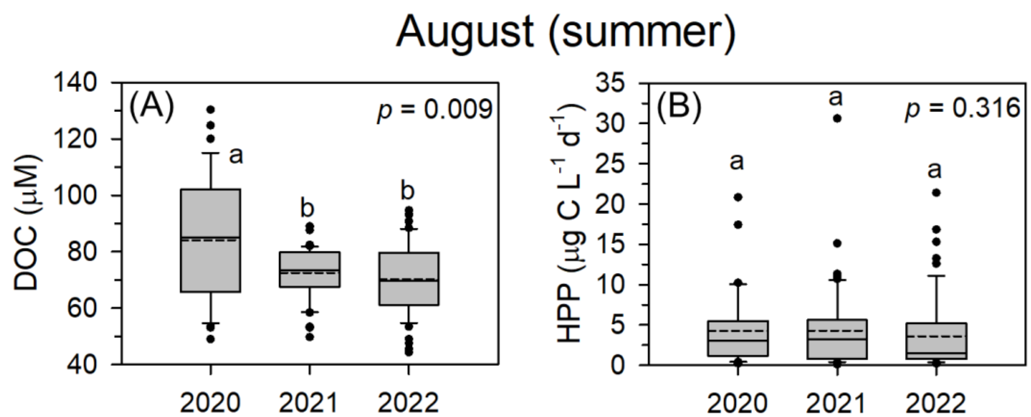

Box plot of dissolved organic carbon (DOC) (A) and heterotrophic prokaryotes production (HPP) (B) in August 2020 – 2022. The solid line in each box indicates the median value, and the dotted line indicates the average value (sample size, n = 36 – 55).

- **The strongest YRDW event in 2020 transported abundant terrestrial DOC, but its refractory nature limited microbial production, indicating a threshold effect in HPP stimulation.**

Key Result 2 I Excessive YRDW input altered DOC bioavailability and limited HPP stimulation

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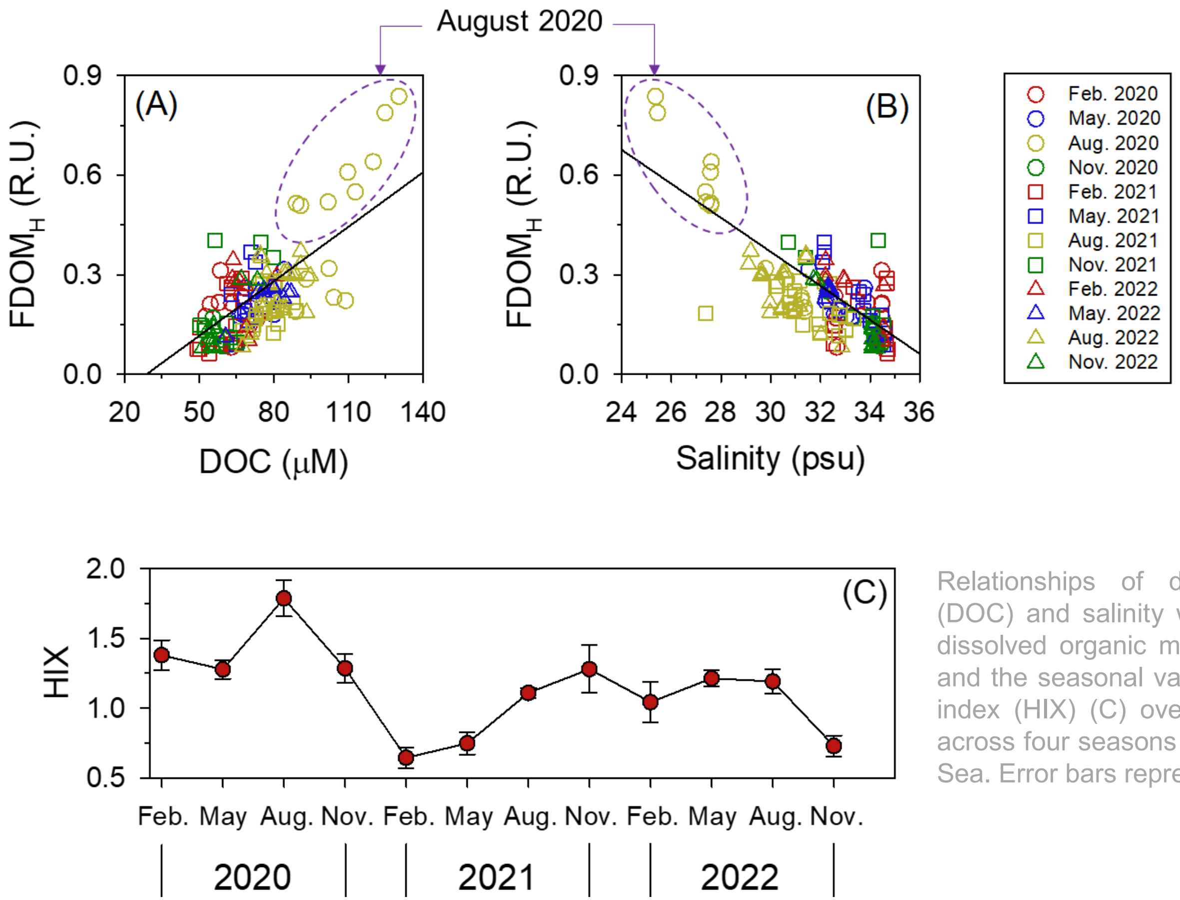

Relationships of dissolved organic carbon (DOC) and salinity with humic-like fluorescent dissolved organic matter ($FDOM_H$) (A and B), and the seasonal variations of the humification index (HIX) (C) over three consecutive years across four seasons in the northern East China Sea. Error bars represent standard errors.

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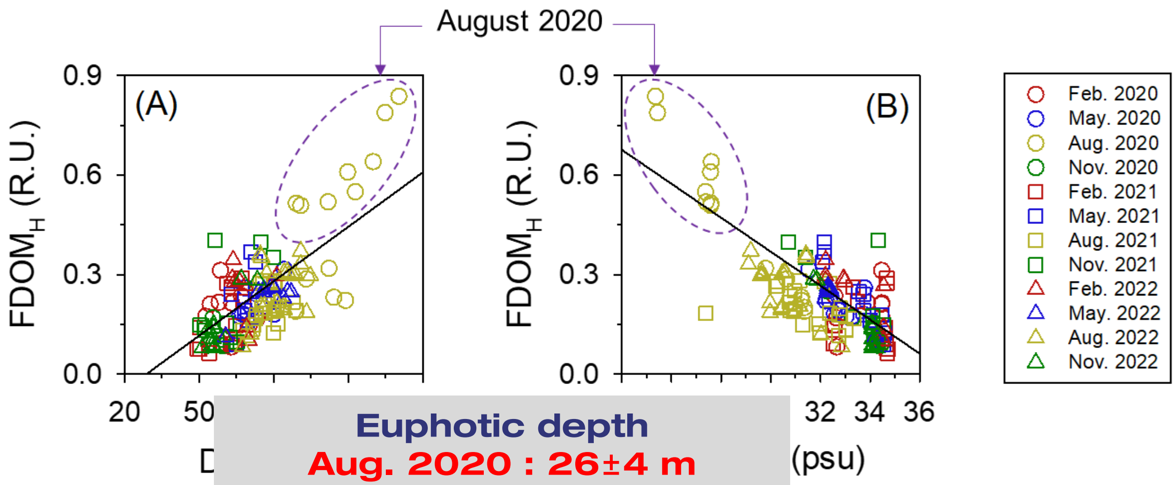
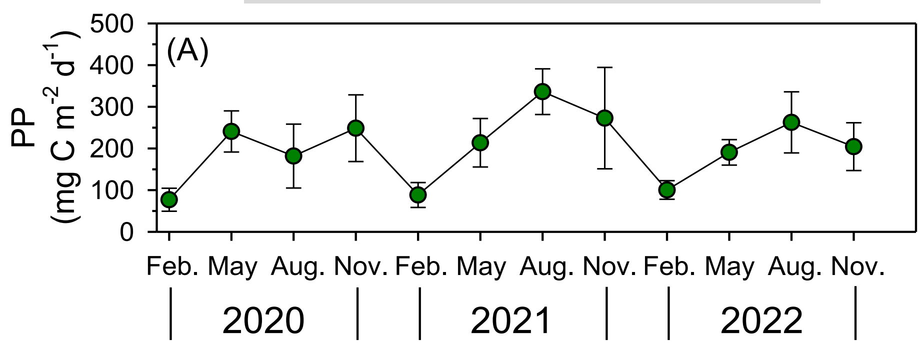


Euphotic depth
Aug. 2020 : 26±4 m
Aug. 2021 : 33±6 m
Aug. 2022 : 34±11 m



Depth-integrated primary production within the euphotic zone in the northern East China Sea. Error bars indicate standard errors.

- **The strongest YRDW event in 2020 transported abundant terrestrial DOC, but its refractory nature limited microbial production, indicating a threshold effect in HPP stimulation.**

Key Result 2 I Phosphorus Limitation by P-depleted YRDW input

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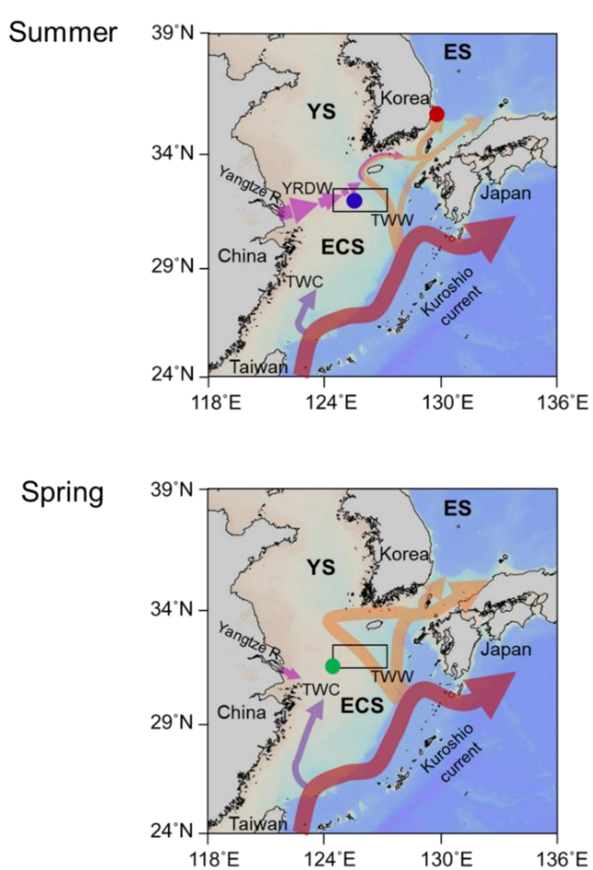

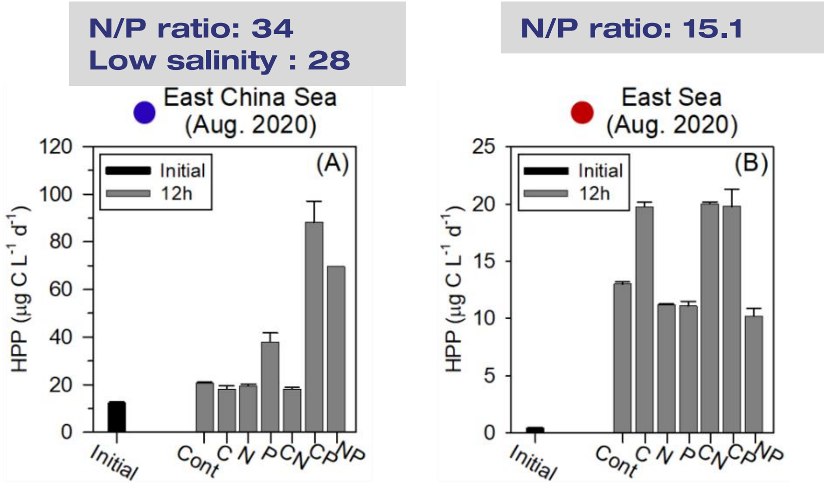

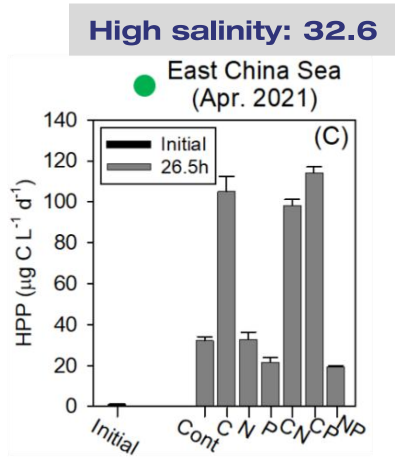

Maps of sampling sites where limiting resource experiments were conducted, and limiting resources for heterotrophic prokaryotes production (HPP) in the East China Sea (blue circle, A) and the East Sea (red circle, B) in August 2020, and the East China Sea (green circle, C) in April 2021.

- **Nutrient enrichment experiments demonstrated that HPP was P-limited under high DOC and high N:P conditions caused by YRDW in summer.**
- **In contrast, under non-YRDW conditions, DOC (carbon) limitation was more evident.**

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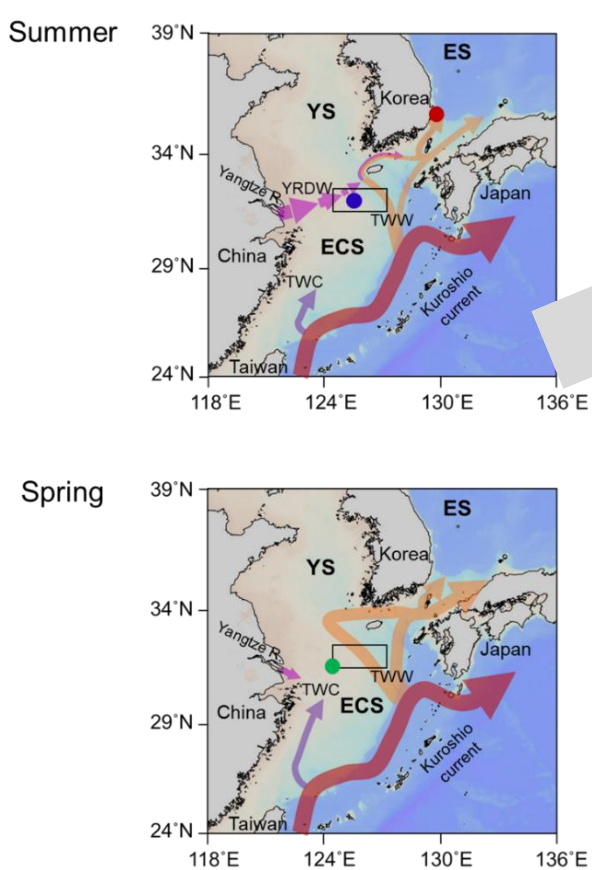
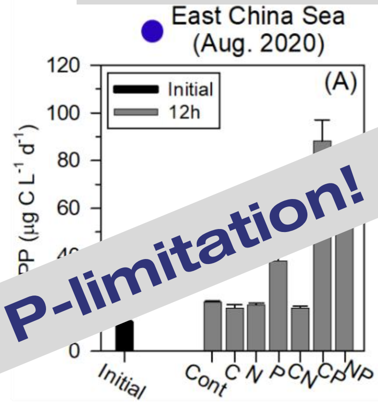
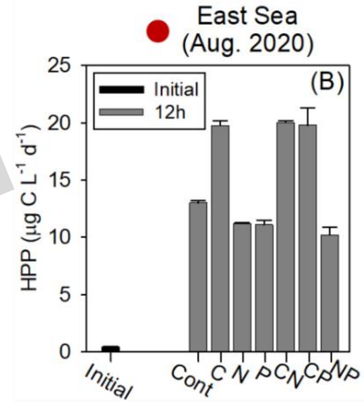


N/P ratio: 34
Low salinity : 28

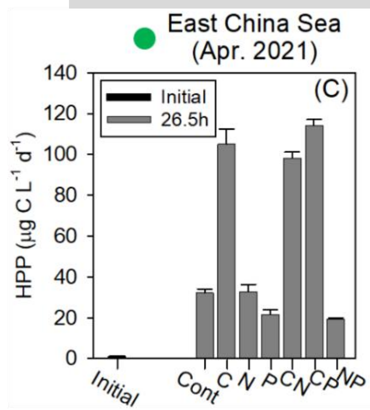


P-limitation!

N/P ratio: 15.1



High salinity: 32.6



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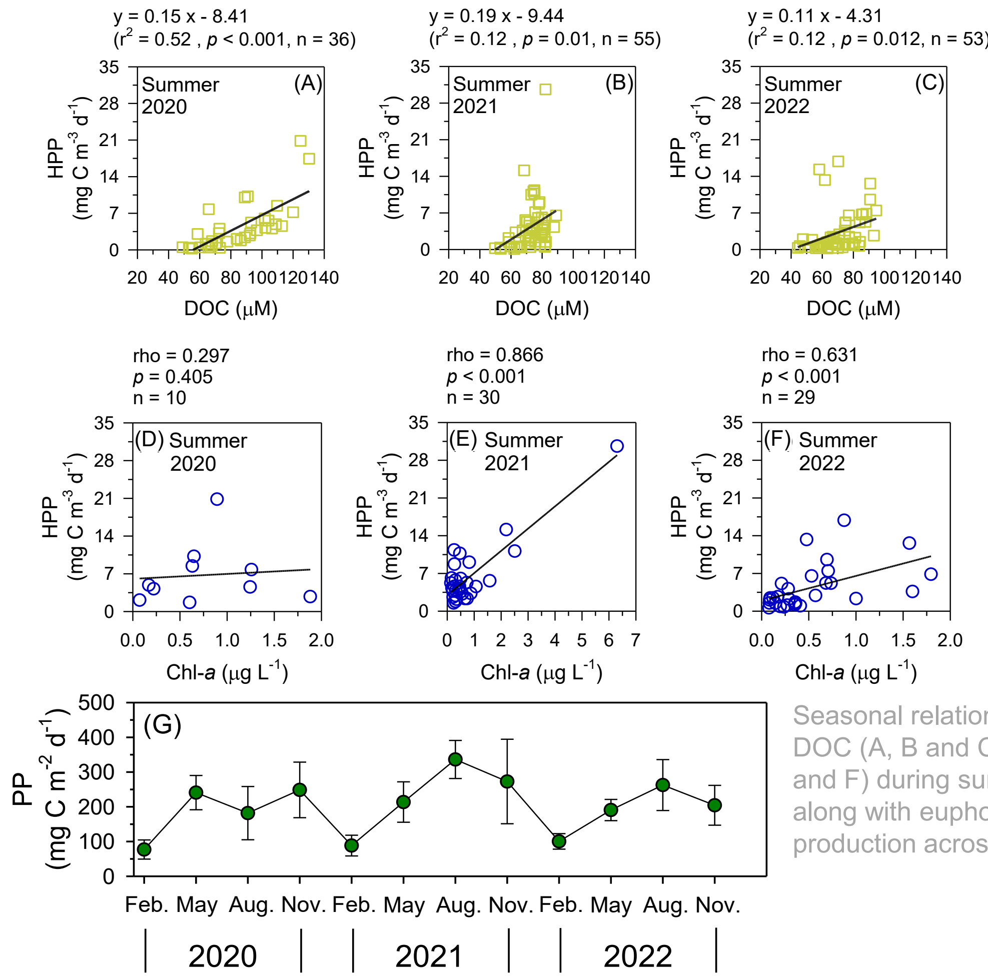
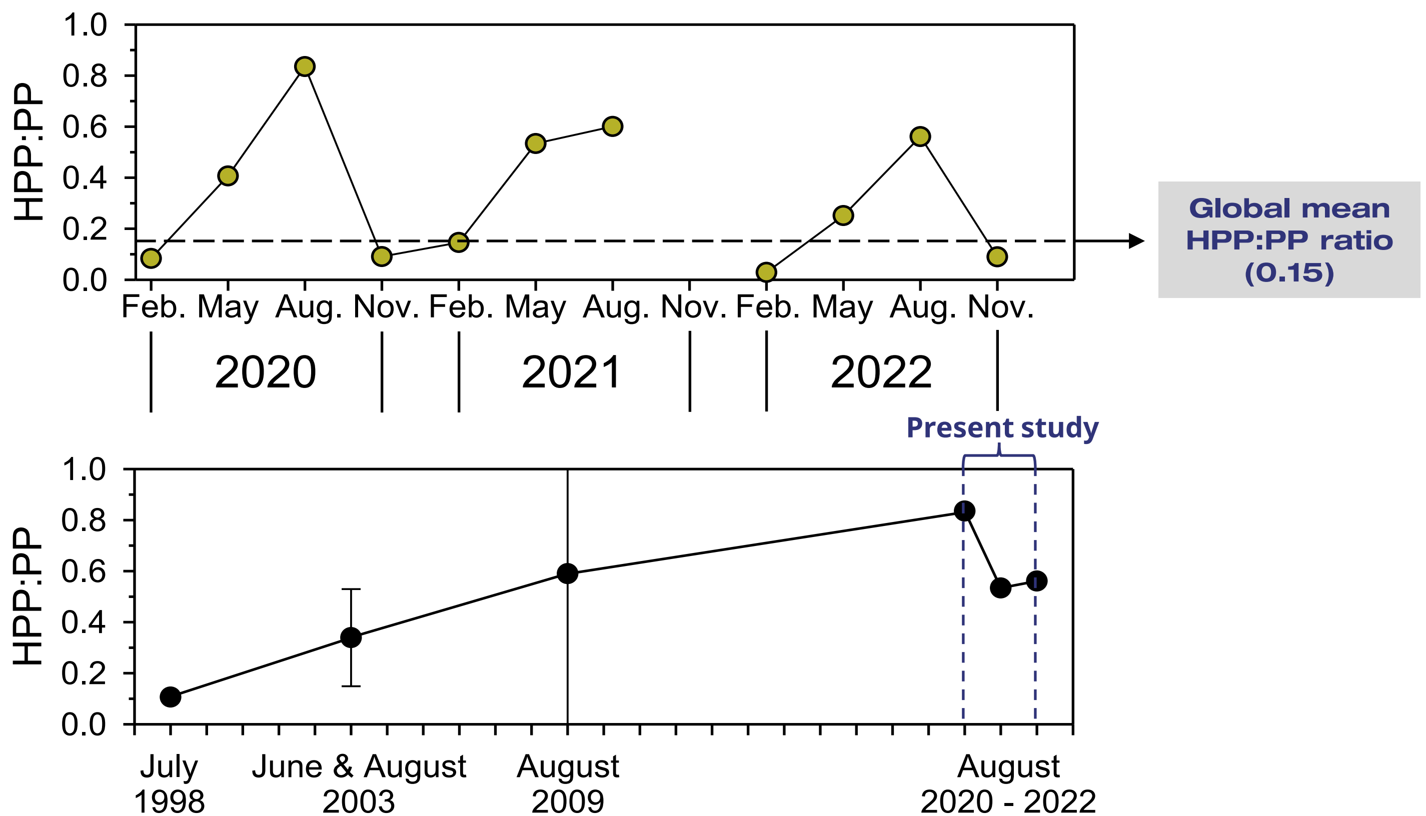


Seasonal relationships between HPP and DOC (A, B and C), and HPP and Chl-a (D, E, and F) during summer (Aug) of 2020–2022, along with euphotic depth-integrated primary production across the three years (G).

- **Severe phosphorus limitation in August 2020 led to a decoupling of primary production and heterotrophic prokaryotes activity.**

Key Result 3 I Increased carbon flow to the microbial food web

***YRDW** - Yangtze River diluted water ***HPP** – Heterotrophic prokaryotes production



Seasonal variations of HPP:PP in the northern ECS and long-term variations in the HPP:PP ratio in the ECS (Data adapted from Shiah et al. 2003; Chen et al. 2006; Chen et al. 2014).

- **Microbial food web is intensified in the ECS, especially under high-precipitation conditions, as shown by elevated HPP:PP ratios over recent decades.**
- **This shift may influence the structure and productivity of fishery resources by favoring microbial-based over classical food web pathways.**

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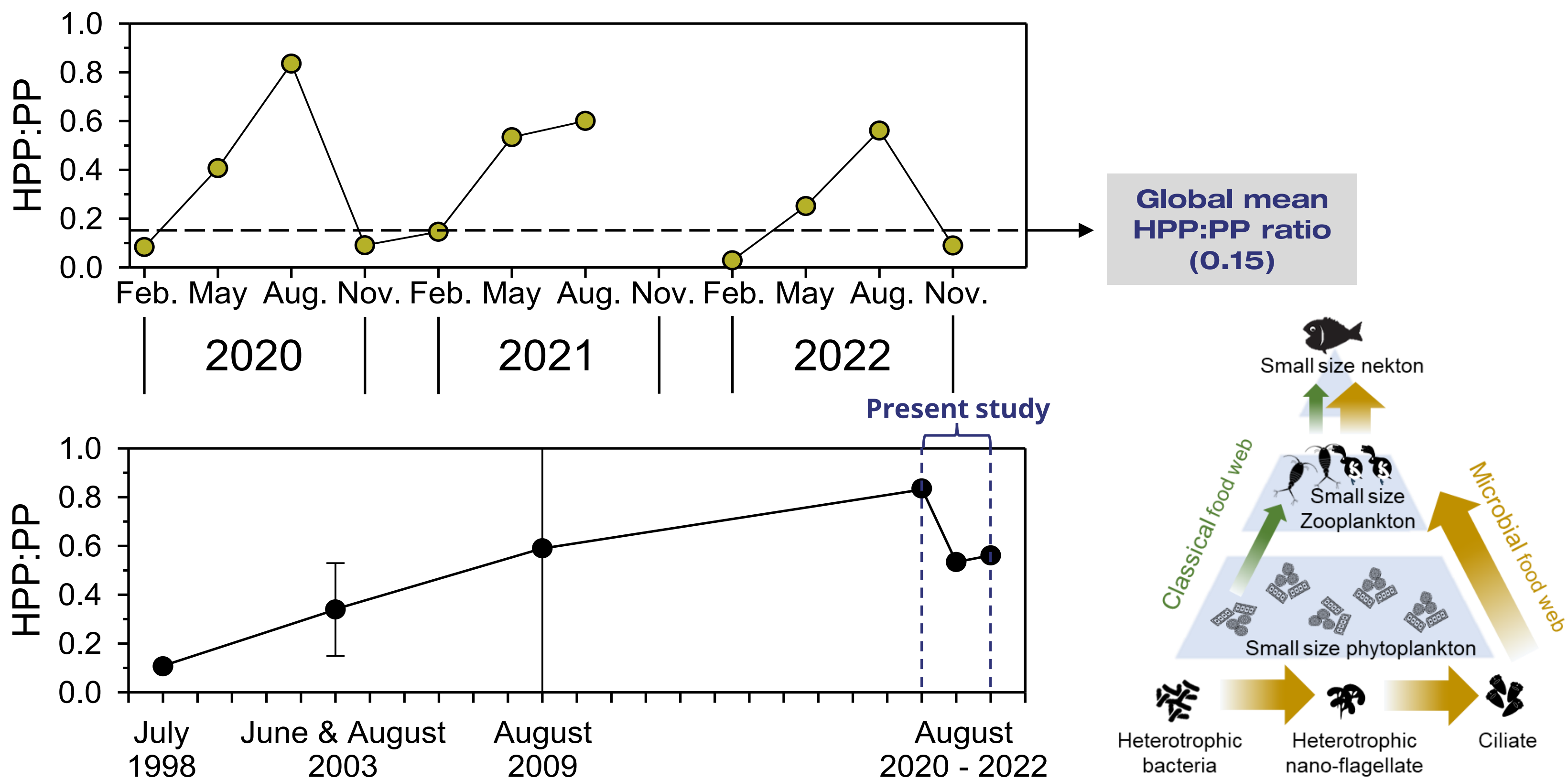

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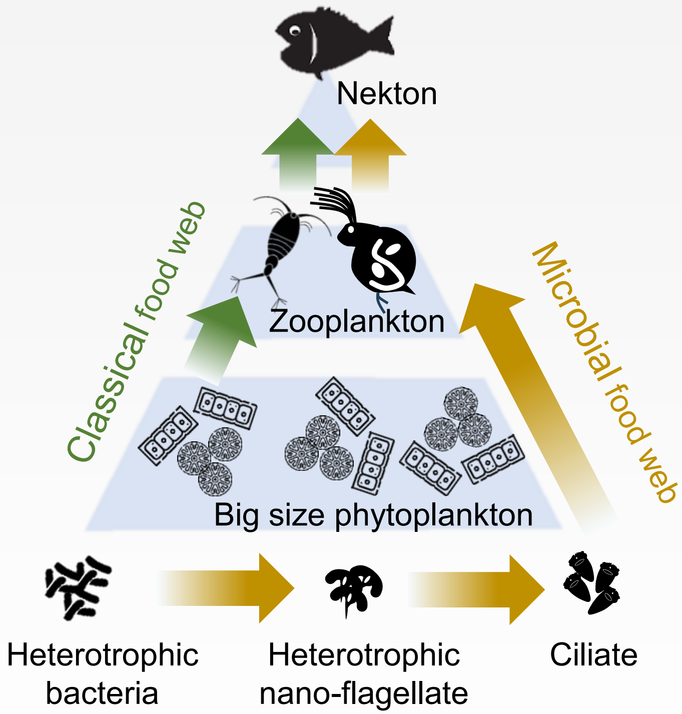
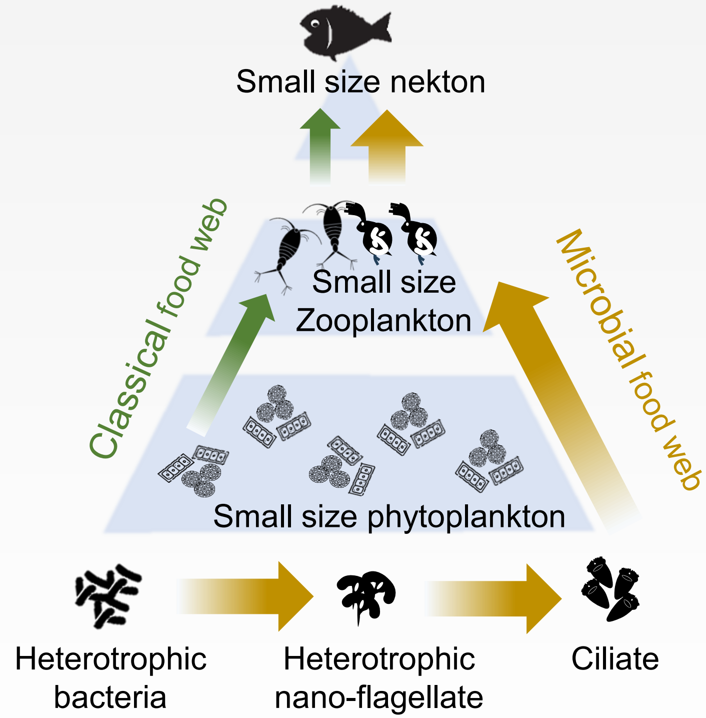
Summary & Conclusion

Moderate YRDW input



DOC supply and nutrient input significantly enhanced both primary production and HPP.

Excessive YRDW input



Refractory DOC and P-limitation set a threshold for HPP and lower primary production.

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Thank you :)