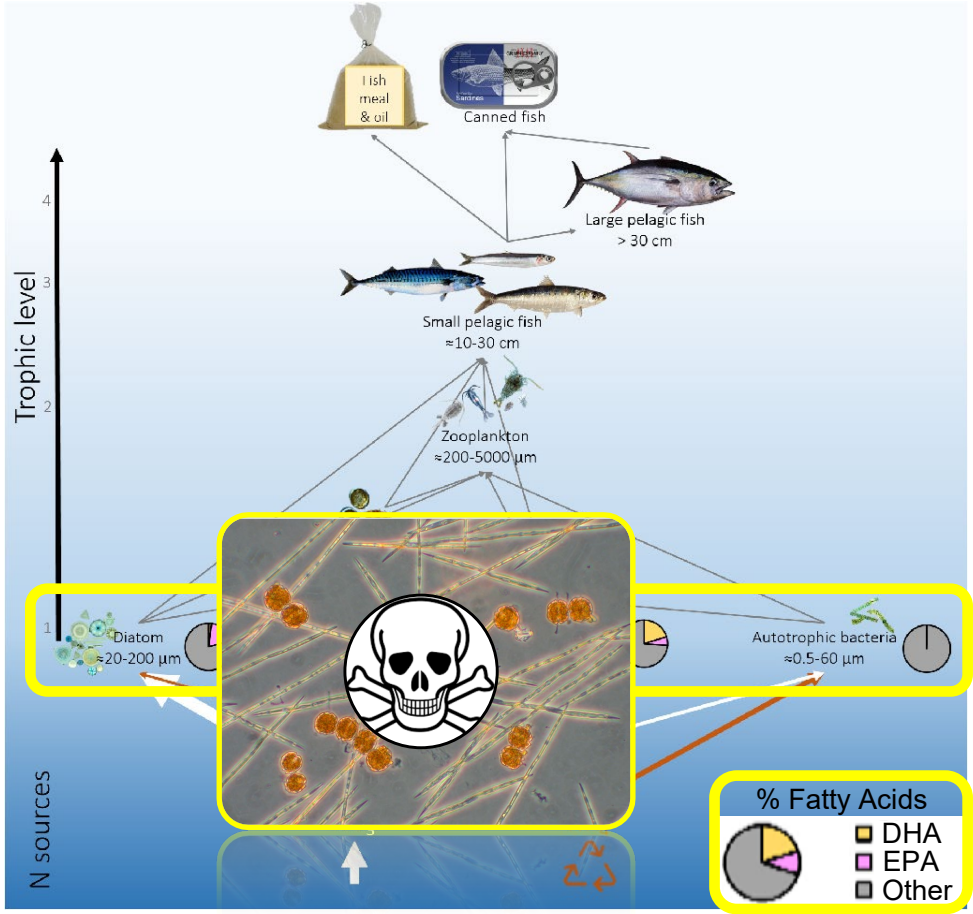
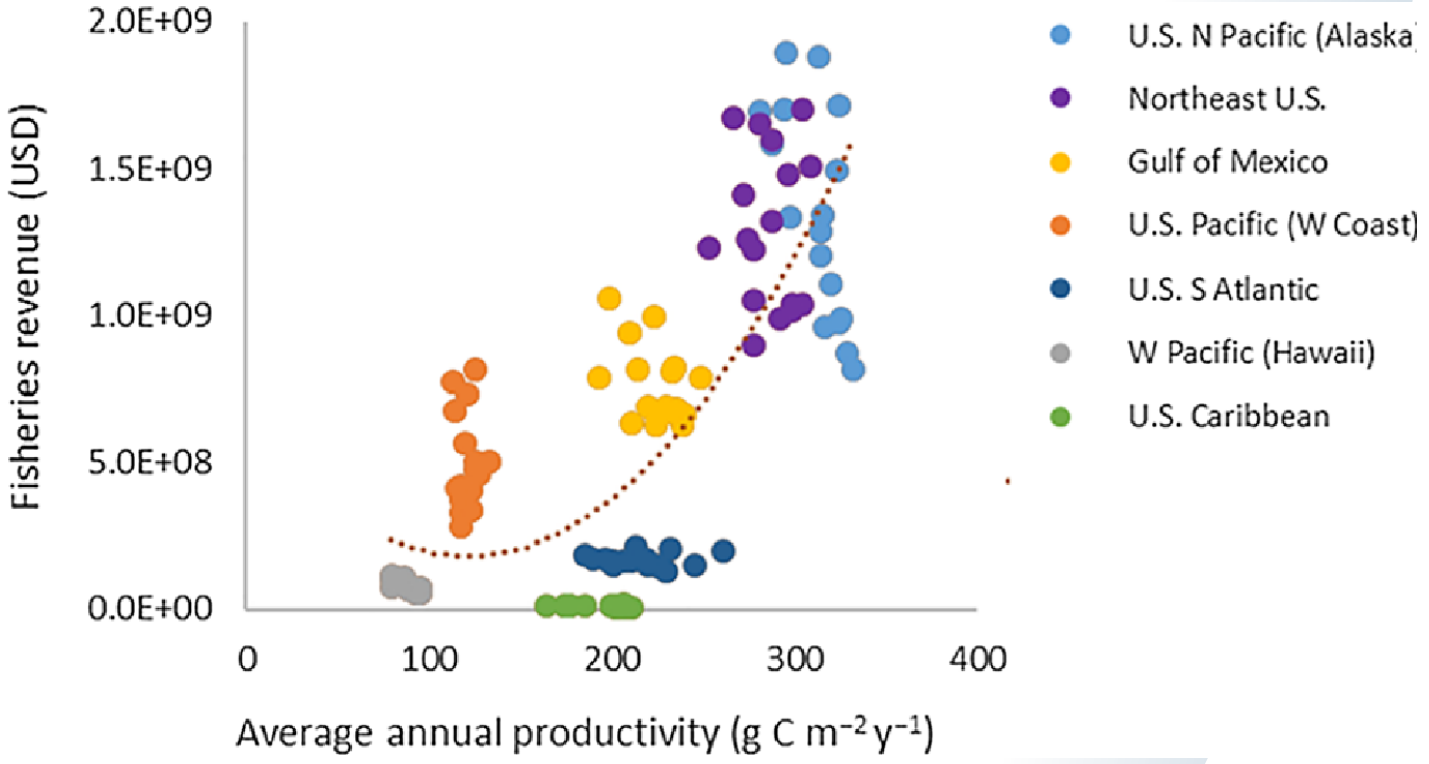
Autonomous sensors for *in situ* monitoring of phytoplankton from fixed & roving platforms in the Pacific Northwest

Stephanie Moore & Nicolaus Adams
Northwest Fisheries Science Center
Seattle, WA

Phytoplankton form the base of the marine food web & may limit fisheries economic performance



Puccinelli et al. (2021): Frontiers in Marine Science



Marshak & Link (2021): Nature

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Harmful algal blooms (HABs) hurt aquaculture, fishing communities & marine wildlife

Dungeness Crabbers Hit Hard By Algae Bloom On Washington Coast

By ASHLEY AHEARN · 18 HOURS AGO

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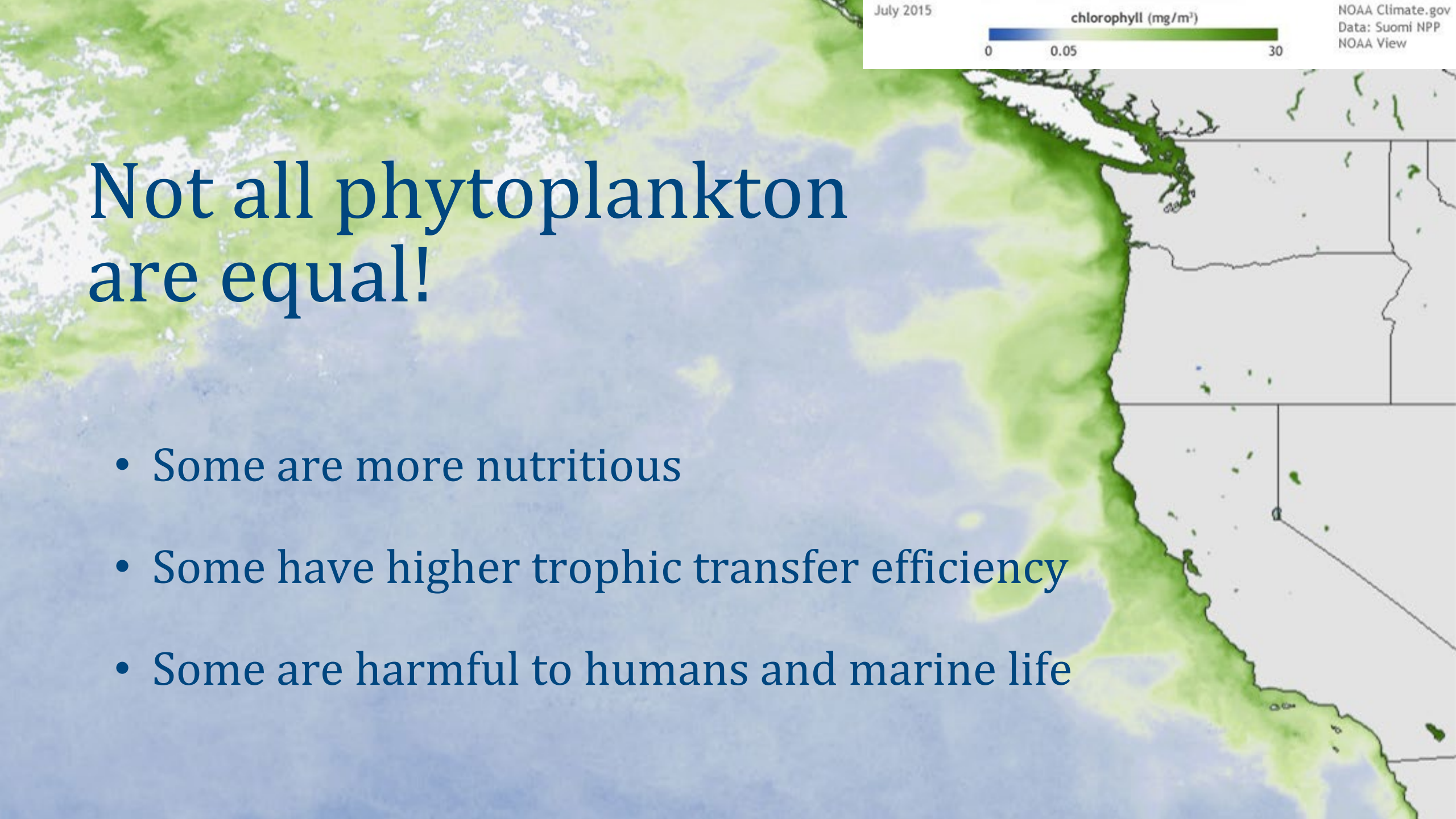
Crabber Tom Petersen would rather have his crab pots on the floor of the Pacific, but a toxic algae bloom has prompted health officials to close the south Washington coast to commercial and recreational crabbing.

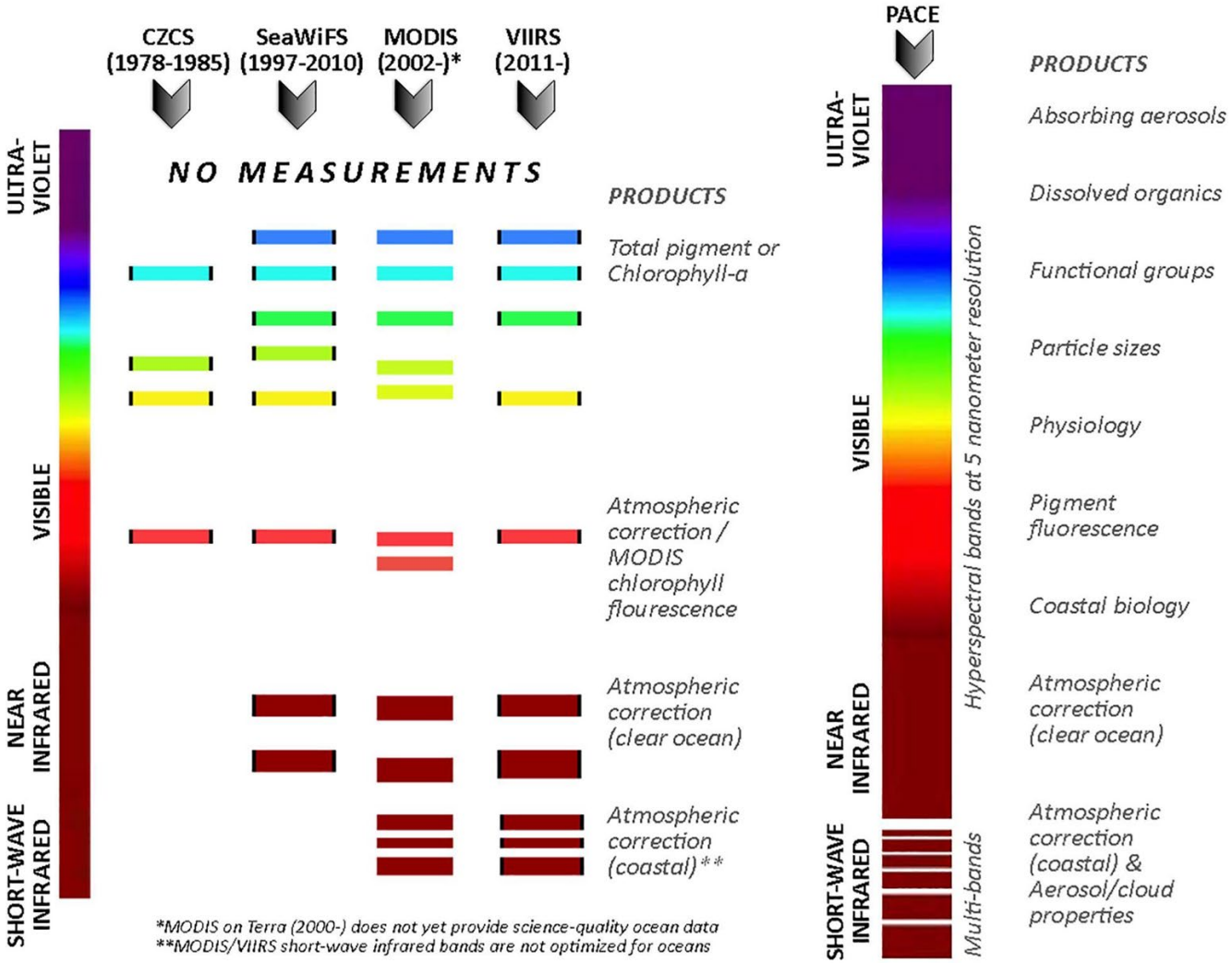
Image credits: Benjamin Drummond /bdsjs.com; Channel Islands Marine & Wildlife Institute



Not all phytoplankton are equal!

- Some are more nutritious
- Some have higher trophic transfer efficiency
- Some are harmful to humans and marine life

SPECTRAL COVERAGE
OCEAN COLOR HERITAGE SENSORS compared with PACE



PACE Plankton, Aerosol, Cloud, ocean Ecosystem

- Difficult to access marine & aquatic environments to obtain samples
- Labor intensive to count & identify species using conventional light microscopy

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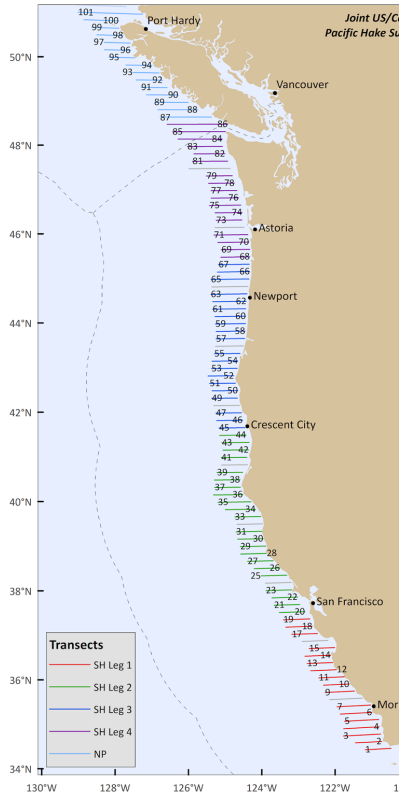
Autonomous sensors for in situ phytoplankton monitoring

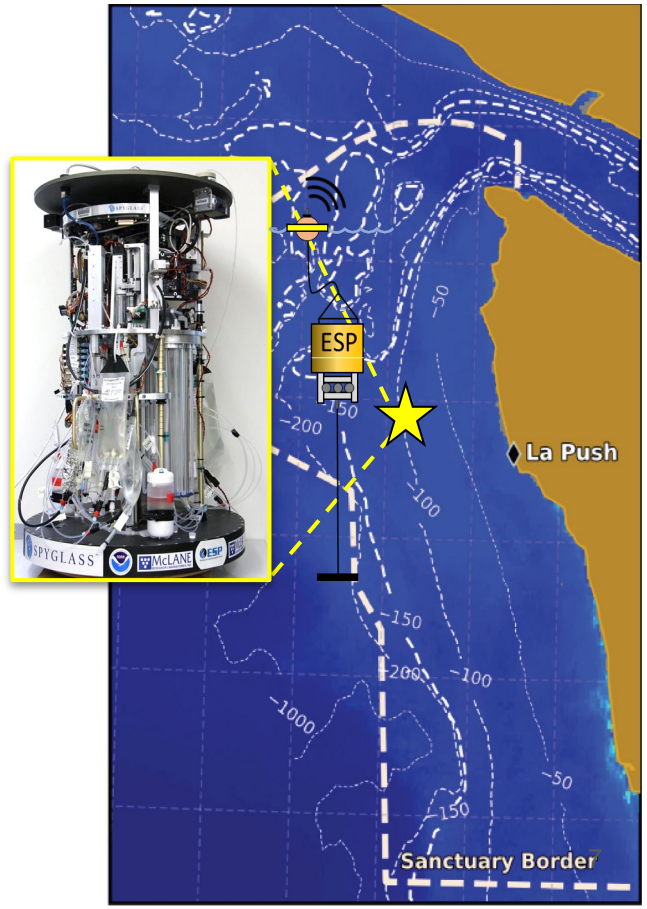
IMAGING FLOWCYTOBOT (IFCB)

Deployed on roving platforms (i.e. fisheries research vessels) off U.S. West Coast



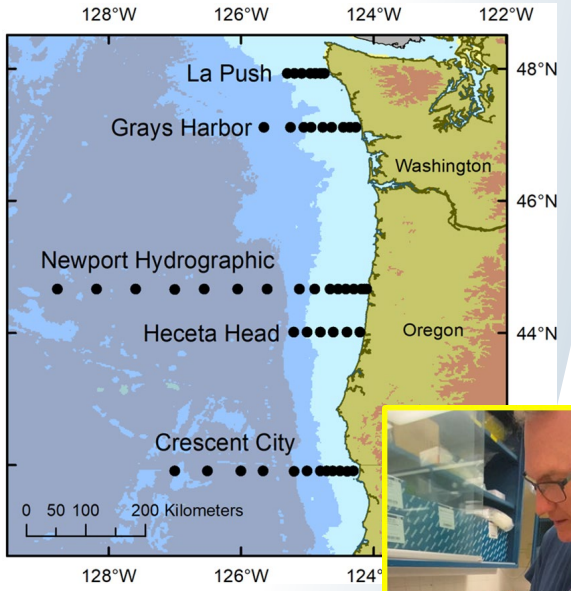
2nd GENERATION ENVIRONMENTAL SAMPLE PROCESSOR (2G-ESP)

Deployed on a fixed platform (i.e. oceanographic mooring) within OCNMS



CONVENTIONAL SHIPBOARD SAMPLE COLLECTIONS

Sample collections on fisheries surveys



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A peek under the hood!

- IFCB and 2G-ESP for monitoring phytoplankton community composition
- Fixed and roving deployment platforms
- Workflows for generating/processing data & data considerations
- Preliminary results from early collaborations with PACE early adopters

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The Imaging FlowCytobot (IFCB)

- Submersible, automated imaging flow cytometer
  - Image acquisition triggered by laser induced fluorescence or light scattering
- Continuous sampling at ~5 mL seawater every 20 min
- Generates ~30,000 images per hour in the size range ~5-150 µm
- Paired with automated image classification models to estimate abundance at species or genus level
- Particle feature extraction (e.g. size, biovolume)

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Integrated West Coast Pelagics Survey

(Formerly the Joint U.S.-Canada Integrated Ecosystem and Pacific Hake Acoustic Trawl Survey)

- Biennial survey in summer (June-September)
- ~110-150 transects oriented east-west along the coast from Point Conception, CA to Dixon Entrance, Canada
- Transects cross the 50-m and 1,500-m isobaths spaced ~16 or 32 km apart
- IFCB data from 2019, 2021, 2023 & 2025

https://habon-ifcb.whoi.edu/timeline?dataset=nwfsc_pacific_hake_survey

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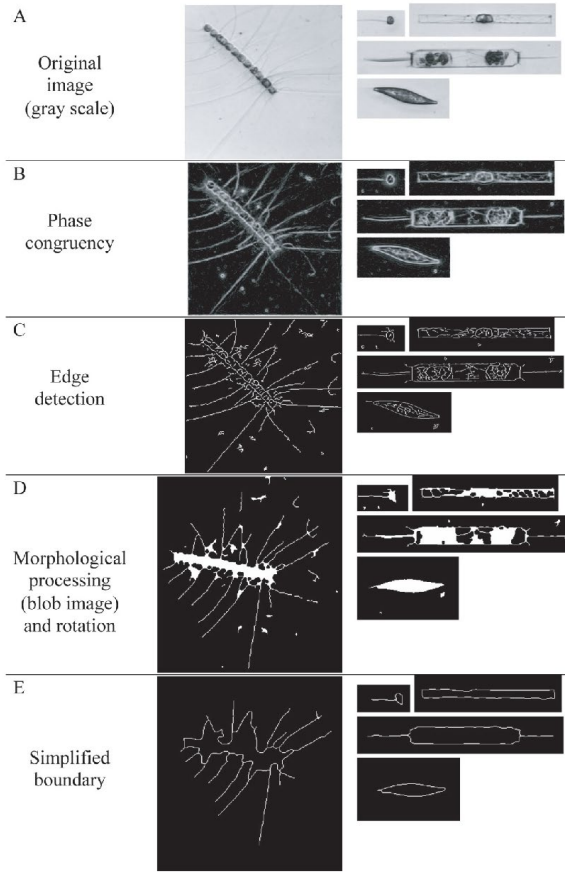
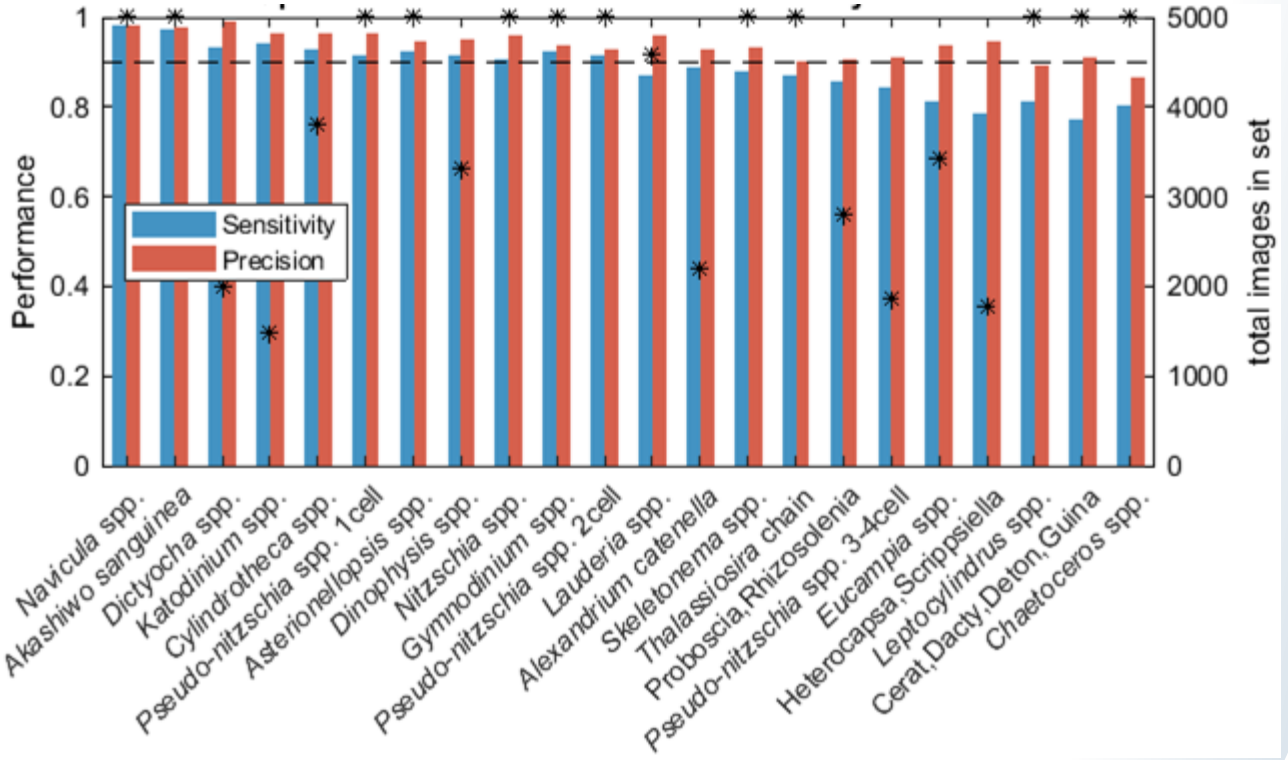
Random forest machine learning classifier automates taxonomic identification of images



Sosik & Olson (2007): Limnology & Oceanography: Methods



Fischer et al. (2024): Limnology & Oceanography

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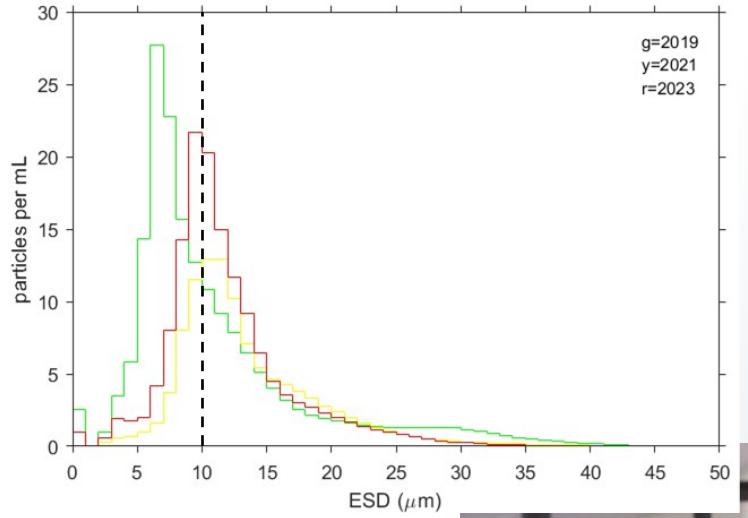
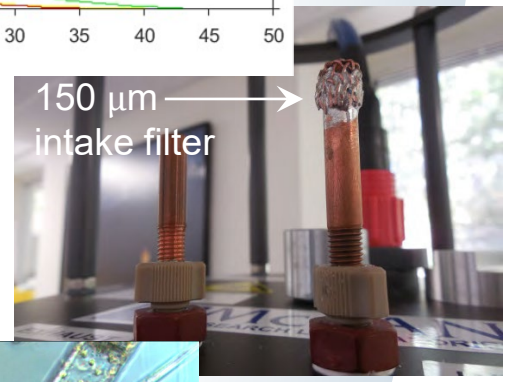
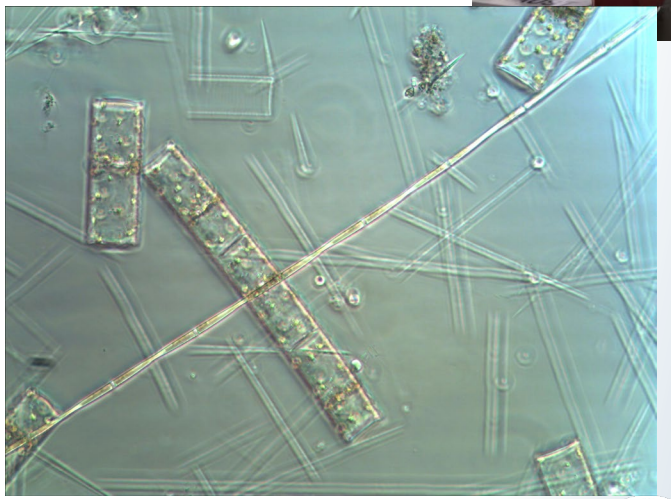
IFCB data considerations

- Does not image small cells (<~6 µm)
- May not effectively image certain cell types
  - Chains, filaments, colonies
- Classifier development/validation requires large image libraries (manual annotation by skilled taxonomist)
- Classifier performance can vary







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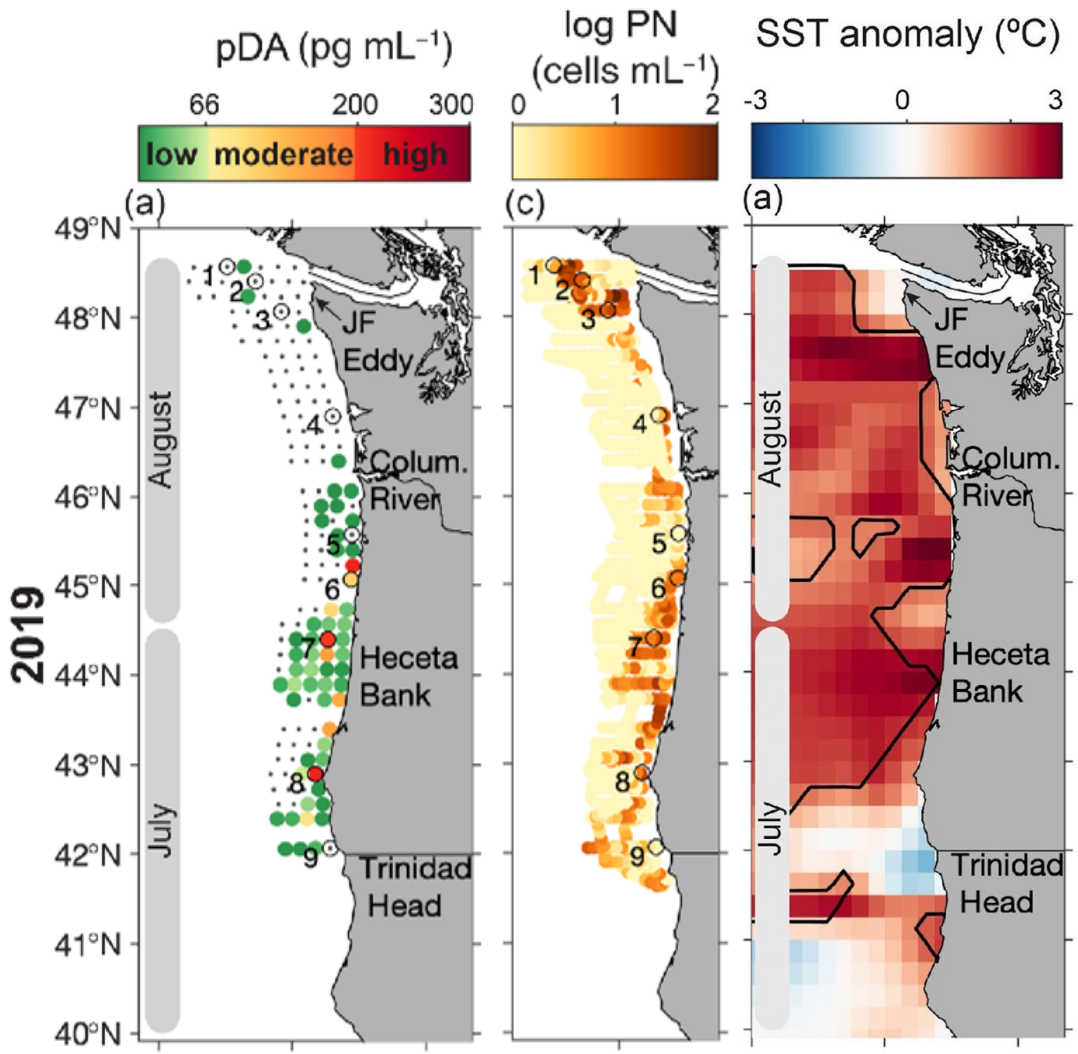
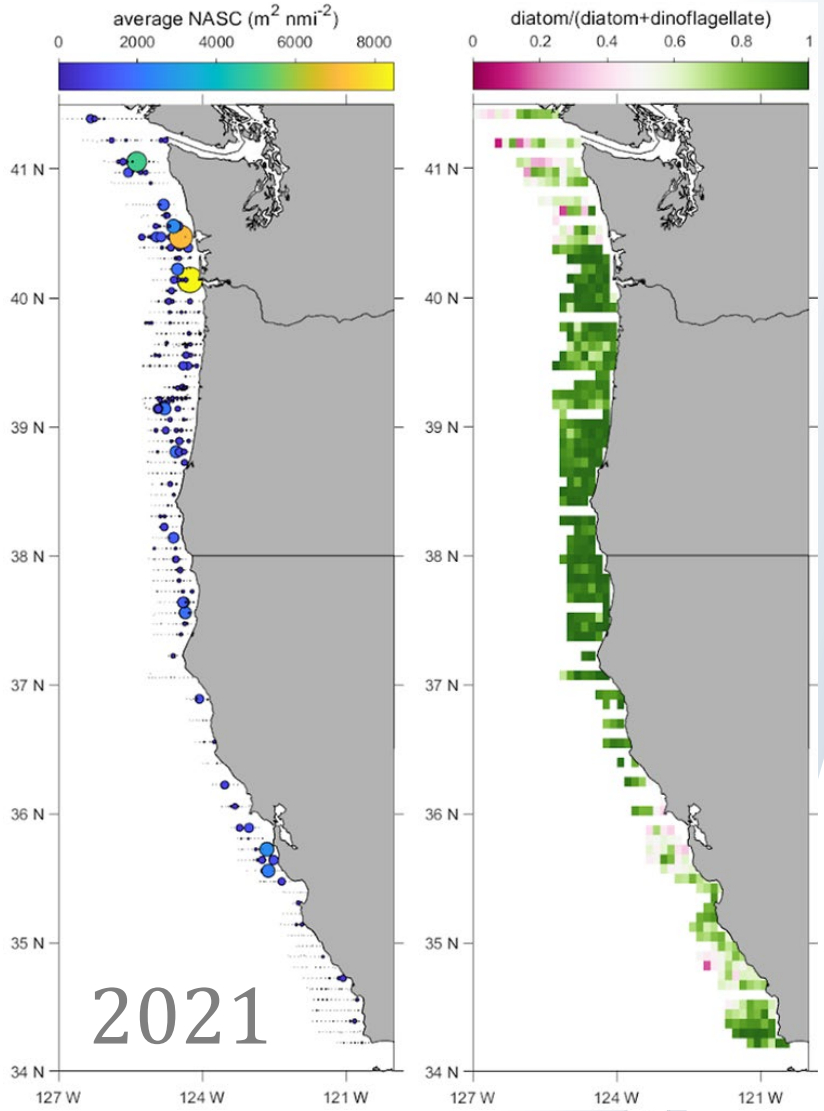
"Nutrient limitation dampens the response of a harmful algae to a marine heatwave in an upwelling system"



Fischer et al. (2024): Limnology & Oceanography

Can phytoplankton community composition predict krill?



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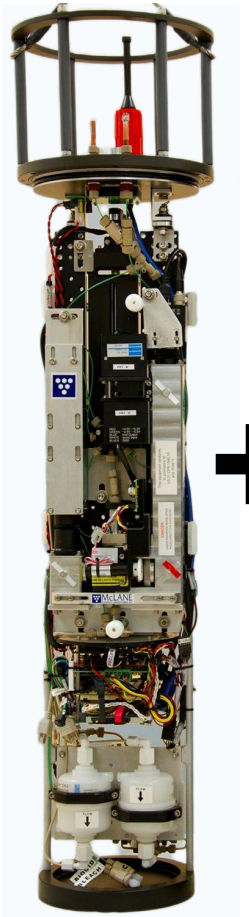
Co-located **D**ynamic **A**bove-water Radiance (**L**) & Irradiance (**E**) **C**ollector (**DALEC**)

Credit: Ryan Vandermeulen (NMFS/OST)



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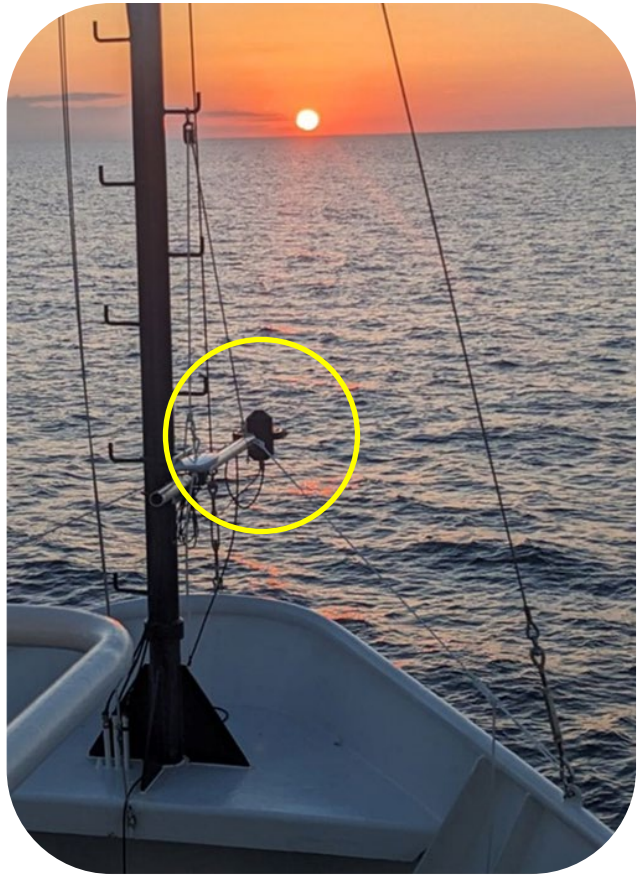

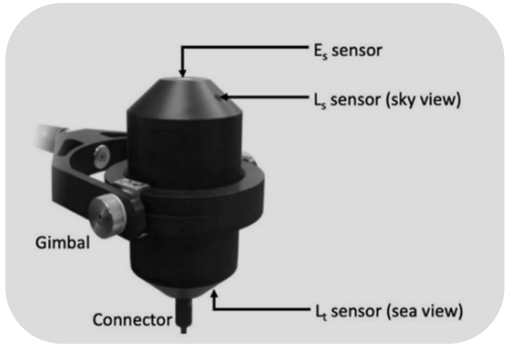

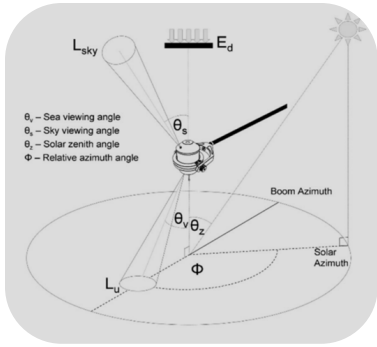

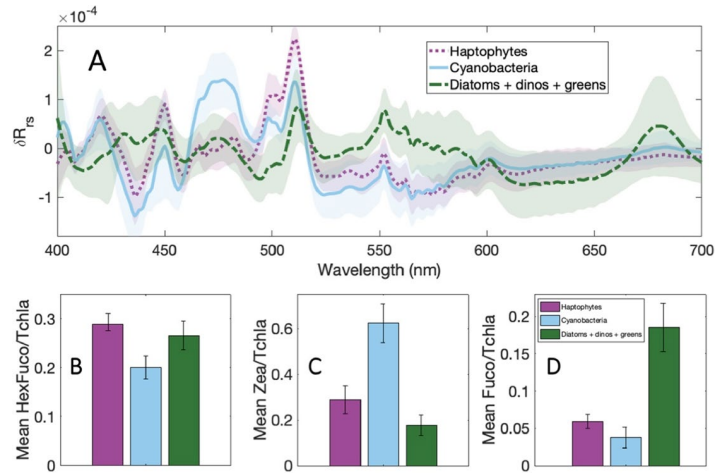

Kramer et al. (2024): Optics Express

Dominant phytoplankton groups can be distinguished with good quality *in situ* hyperspectral data

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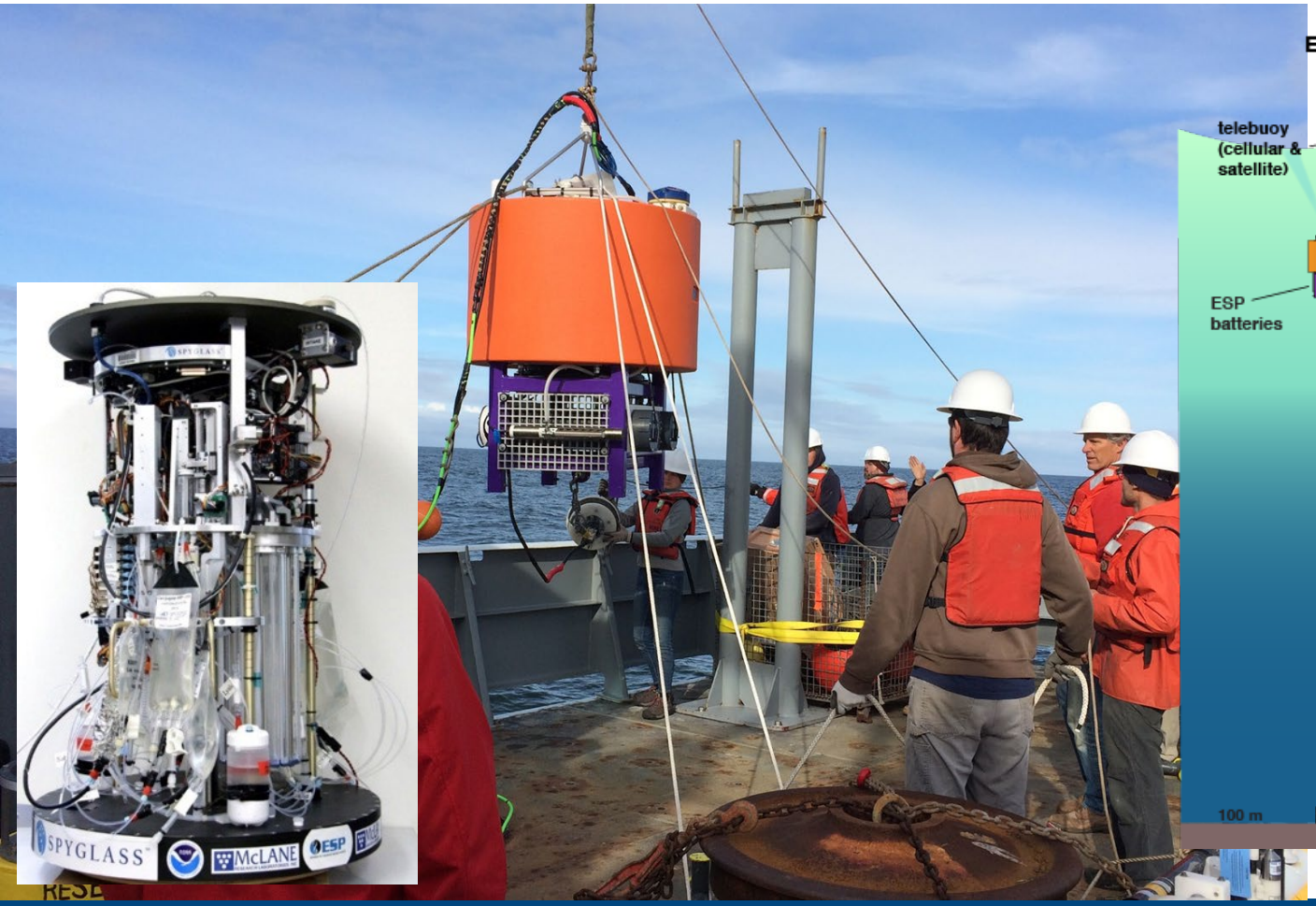
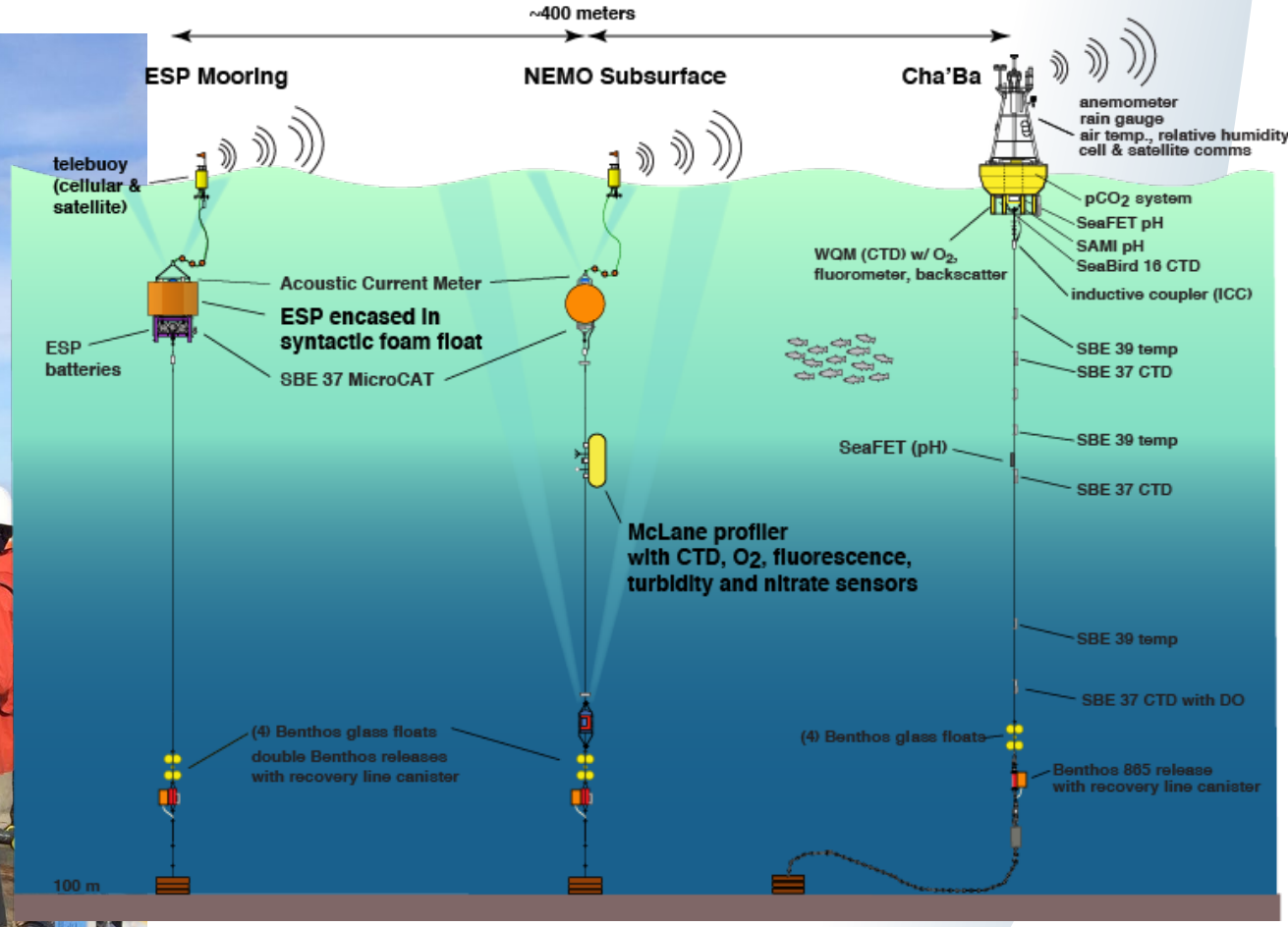
The 2nd generation Environmental Sample Processor (2G-ESP)





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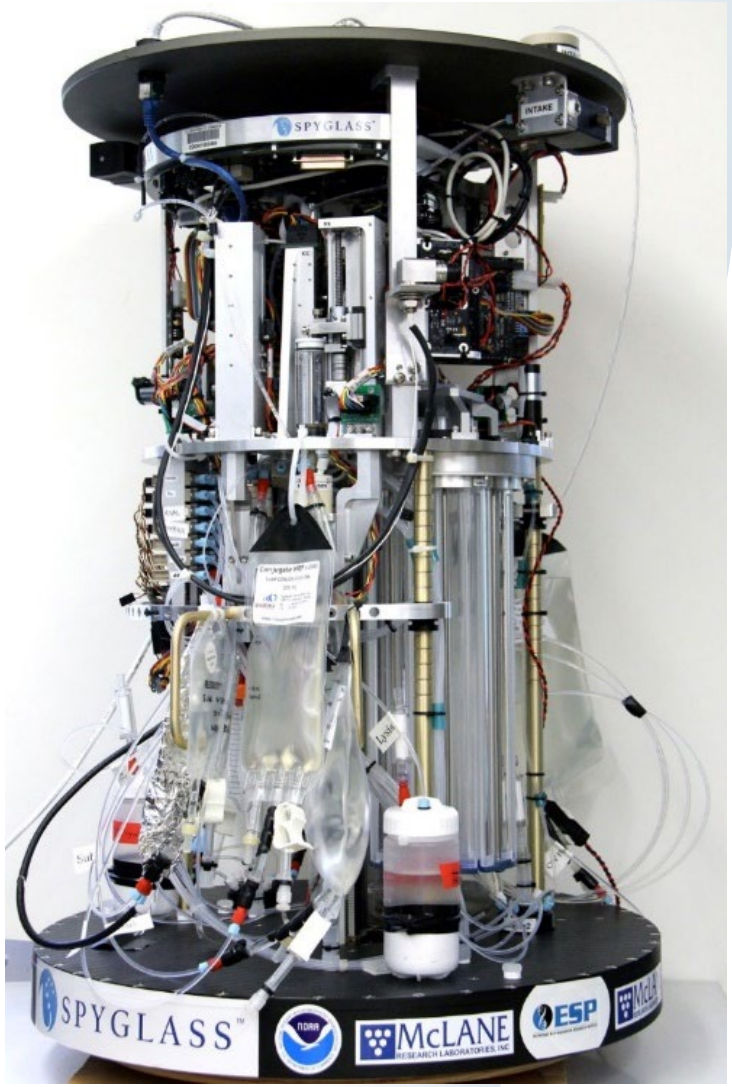
2G Environmental Sample Processor

- On board molecular assays for real-time detection of species and biotoxins
- Archives for eDNA
- Up to 198 samples/deployment
- Programmable
- 2-way remote communication
- Fixed platform (moored or shore-based)
- Up to 6 month deployment duration**



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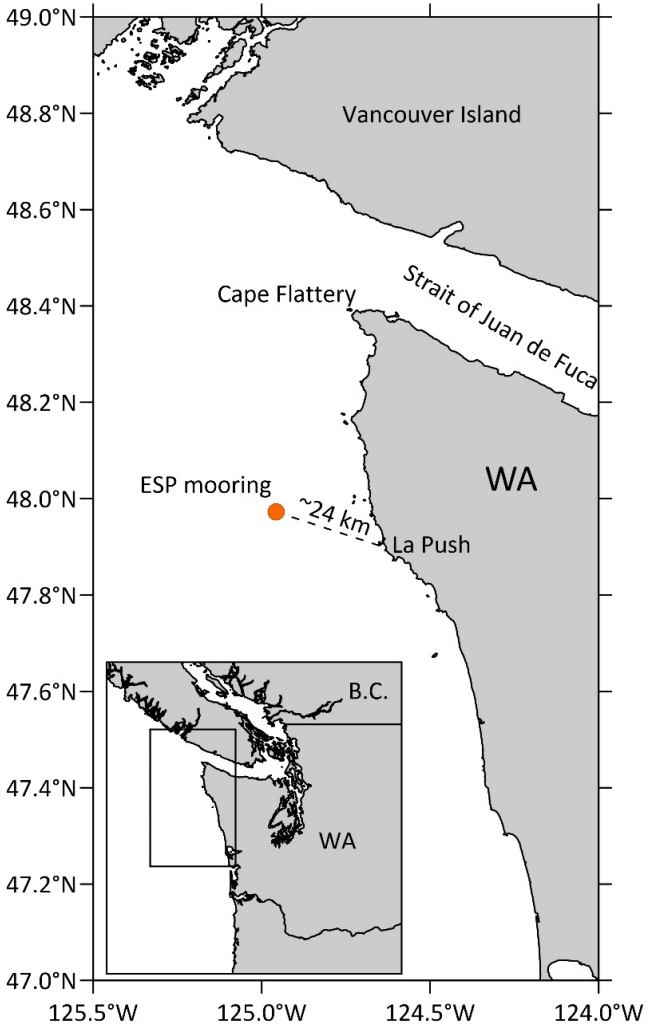
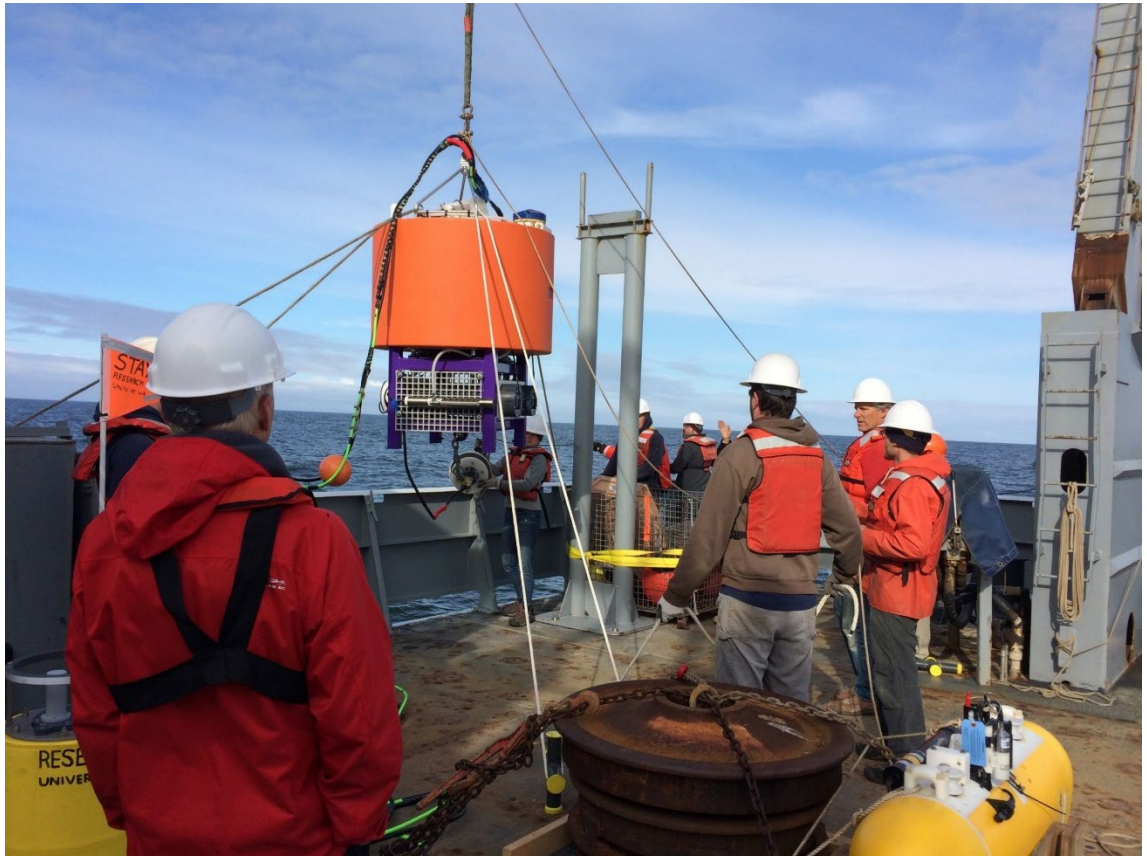
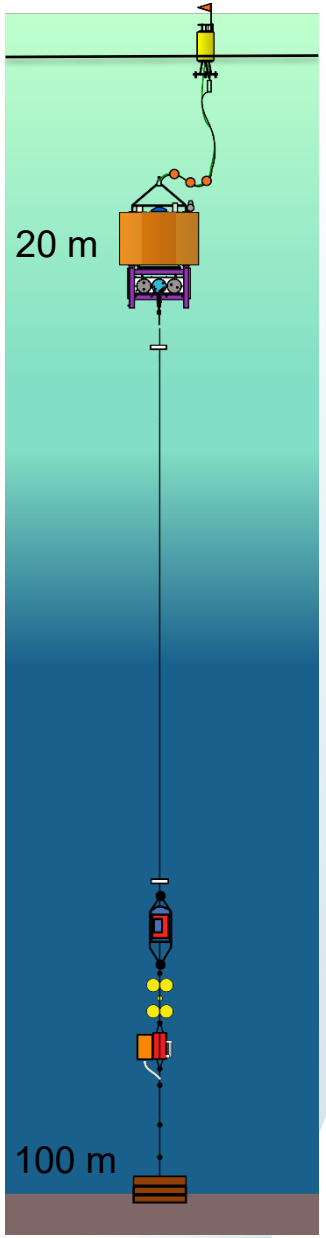
NWFSC 2G ESP sampling for eDNA







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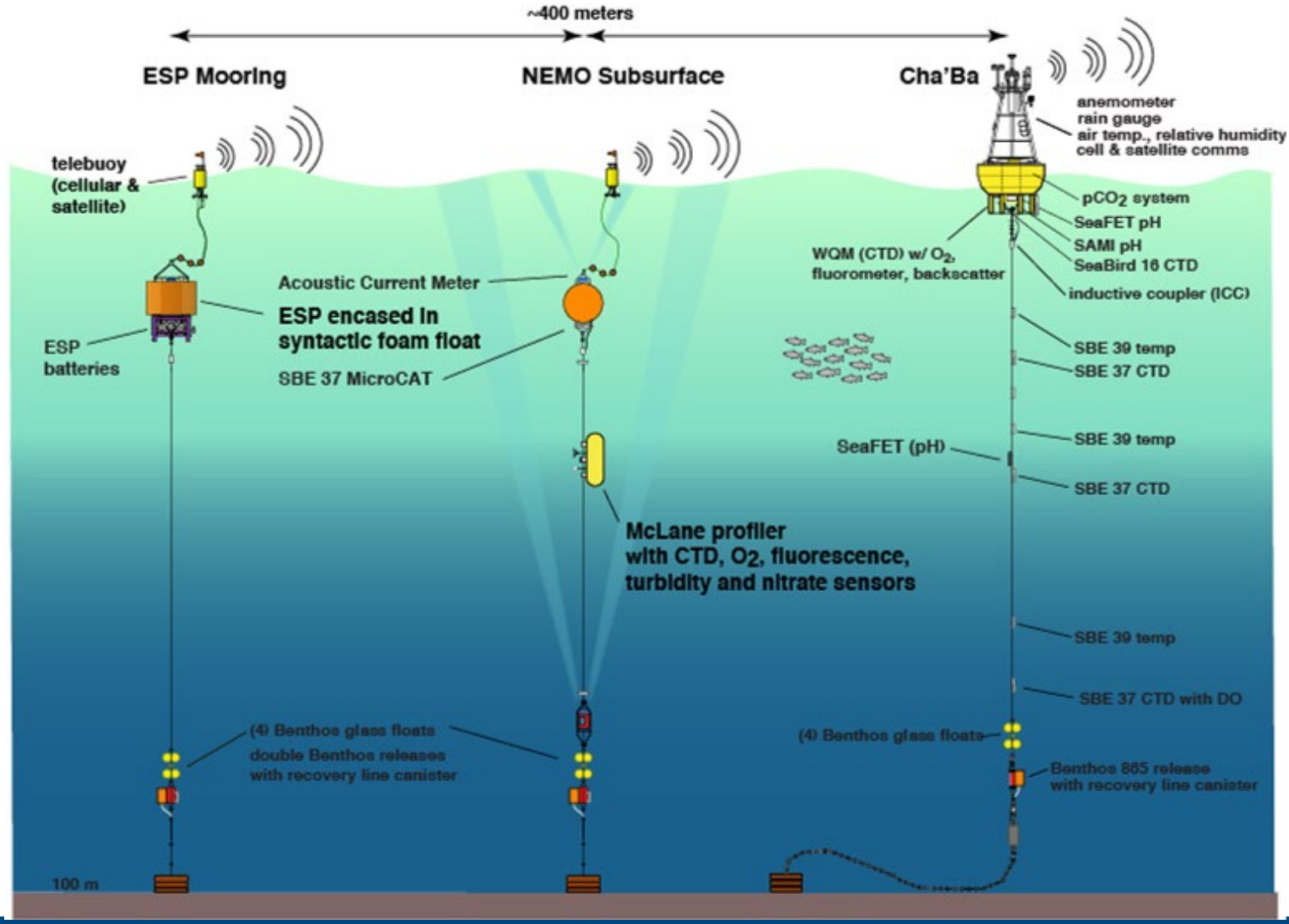
NEMO Observatory



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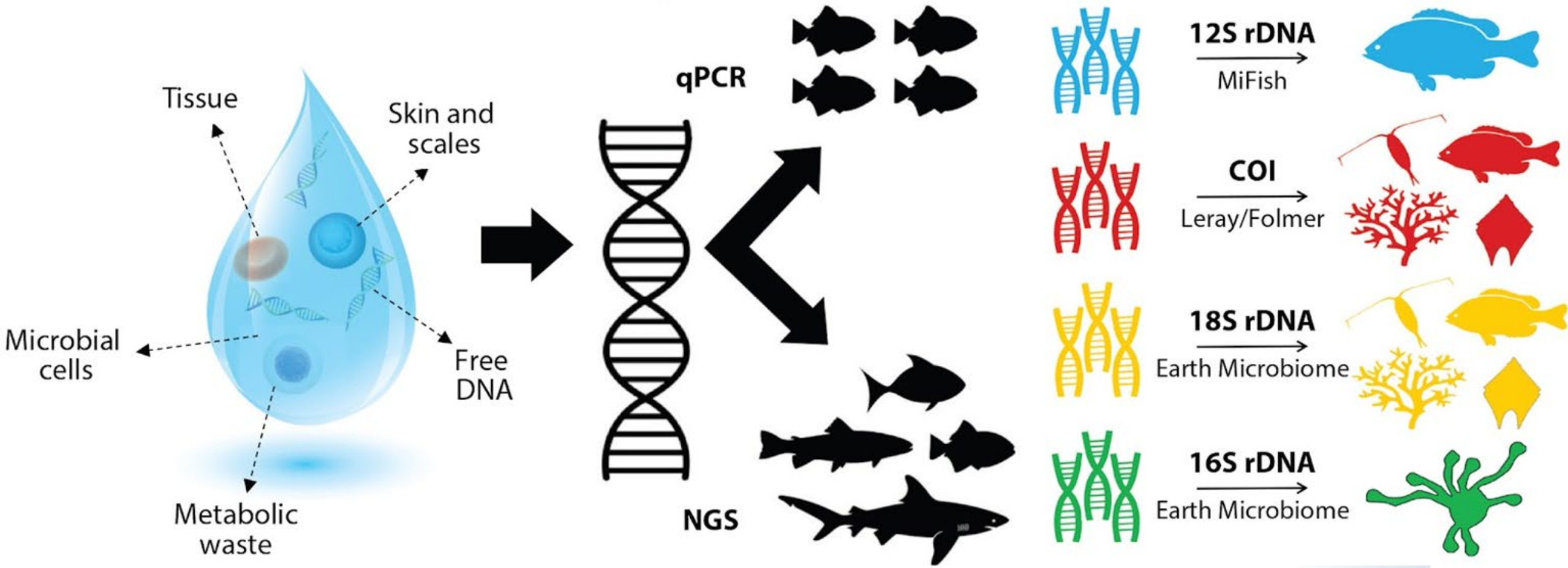
eDNA



Credit: Kevan Yamahara, https://www.mbari.org/project/environmental-genomics/

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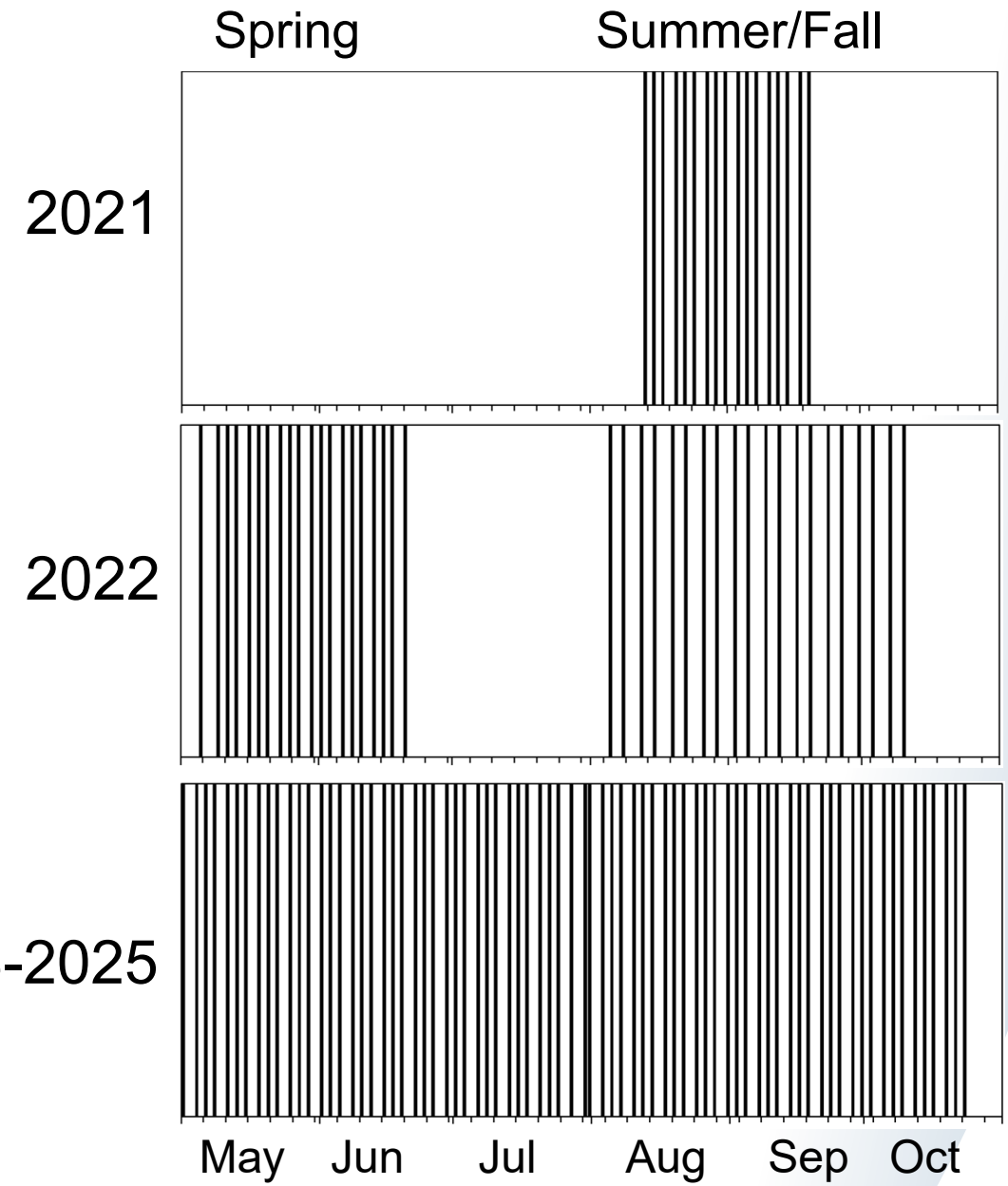
2G-ESP eDNA samples

- Beginning Summer 2021
  - 25 mm, 0.22 µm filters
- Up to 1 liter of water (but often times less)
- To date 323 samples collected at this location



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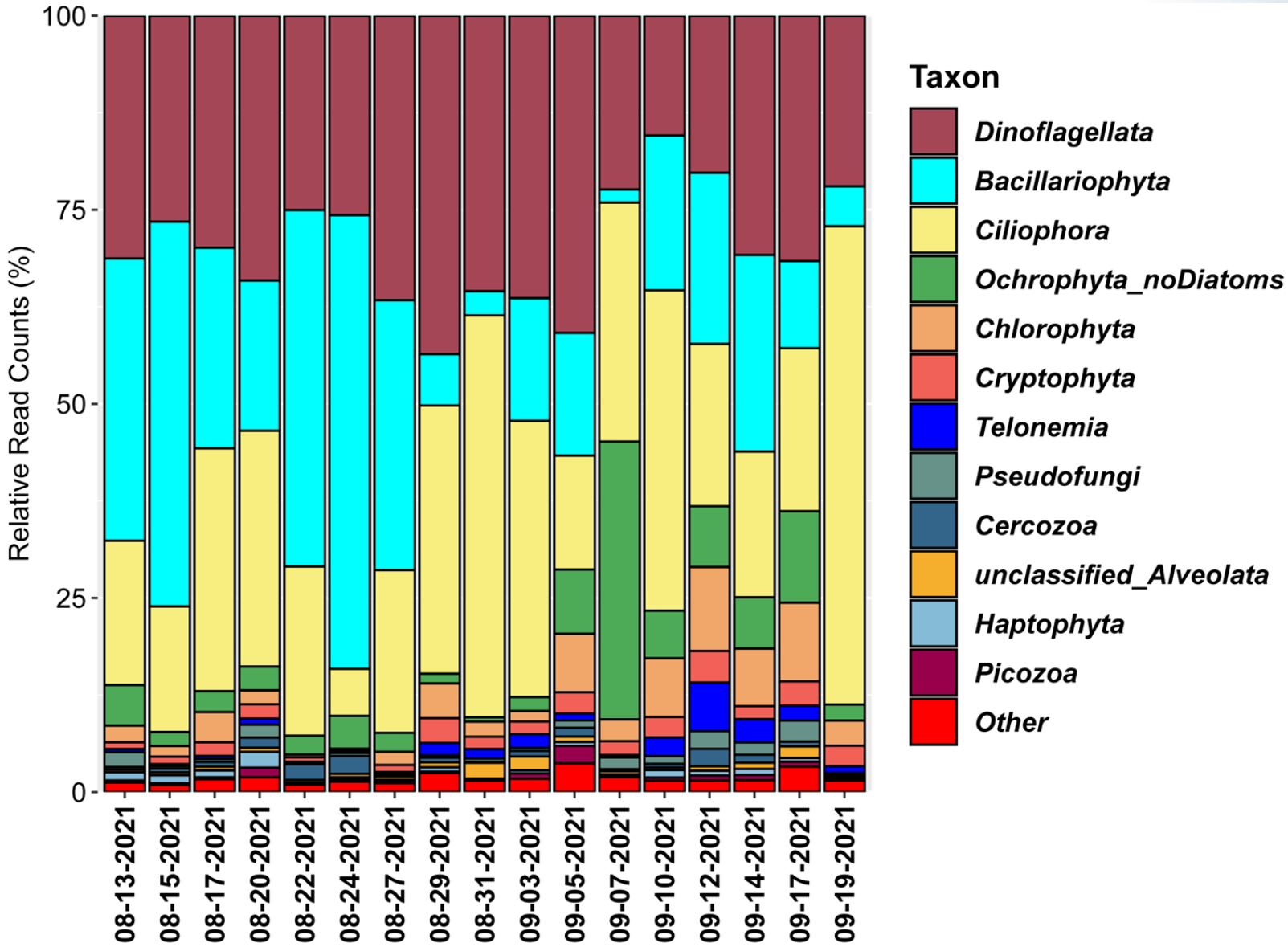
2021 eDNA Data

- 18S V9: phytoplankton
- Variable community structure
- Considerations:
  - Compositional
  - Relative abundance
  - Sequencing depth
  - Volume filtered
  - Not quantitative



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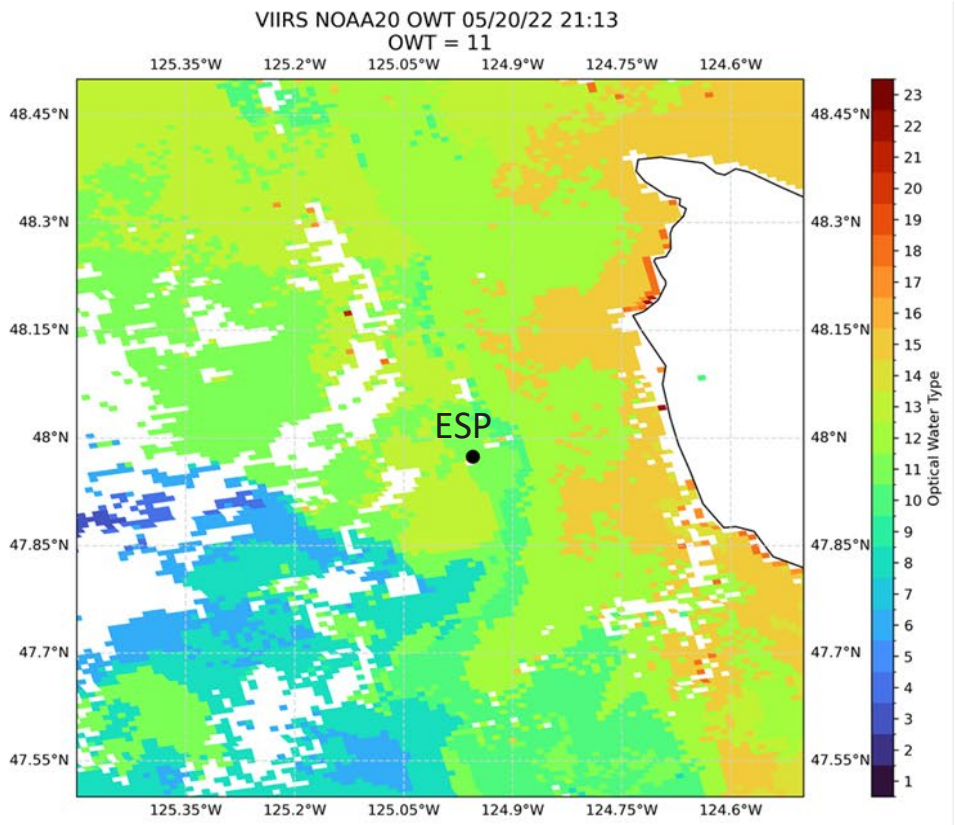
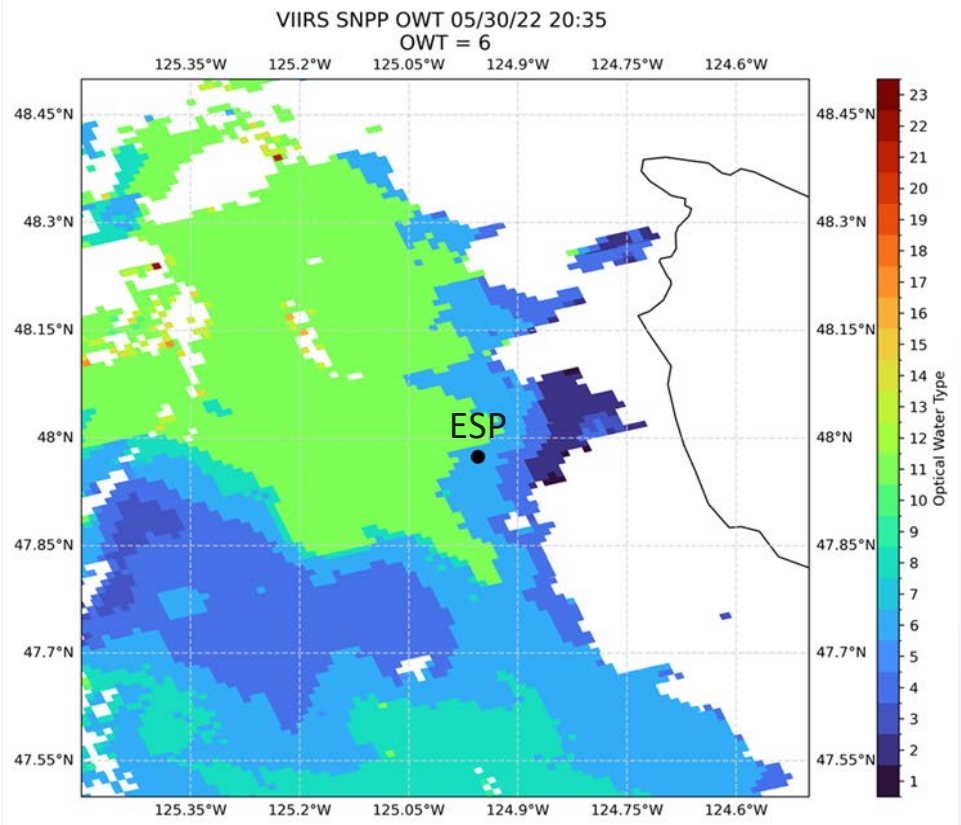
Multi-spectral Optical Water Classes* at the ESP location

Proof of concept for applying Optical Water Class to the new hyperspectral PACE sensor





*Wei et al., 2022: https://doi.org/10.1016/j.rse.2022.113233

Credit: Rebecca Trinh & Jonathan Sherman (NESDIS/STAR)

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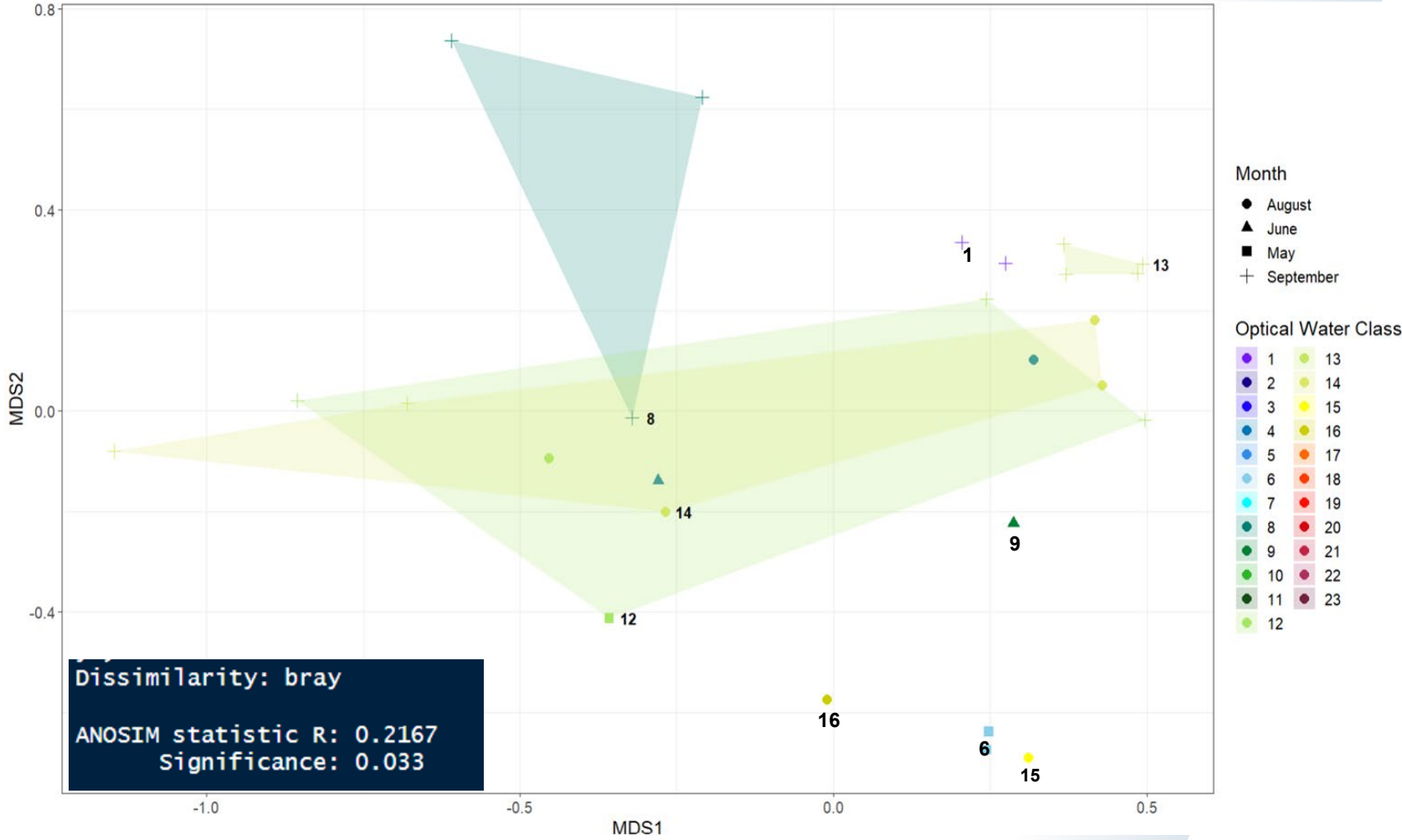
Non-metric Multidimensional Scaling (NMDS) Analysis

- Significant relationship between phytoplankton taxa and Optical Water Class
- Distinct phytoplankton communities are associated with distinct water masses that are detectable from space



Credit: Rebecca Trinh & Jonathan Sherman (NESDIS/STAR)

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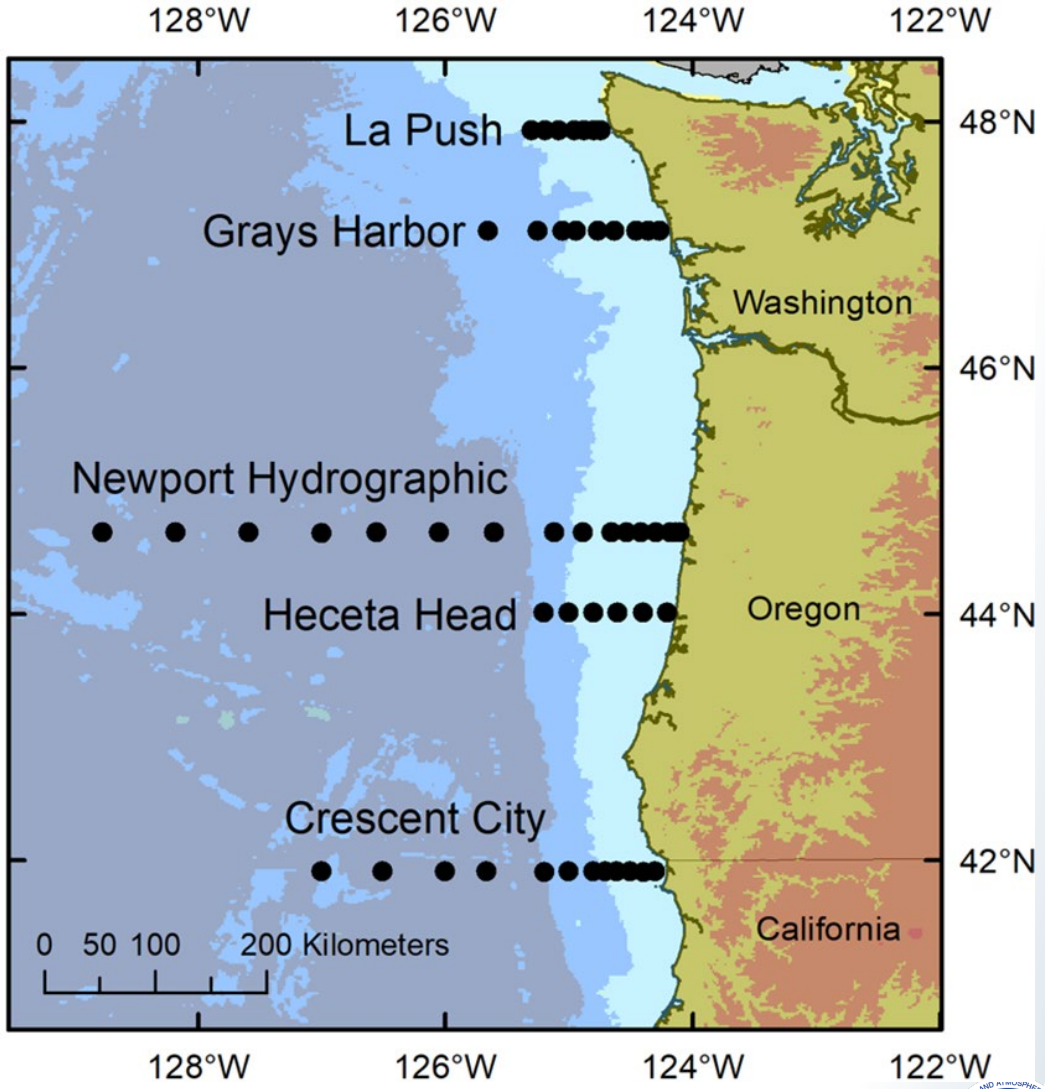
Shipboard eDNA collections

- Northern California Current
- 2020-2025
- May and September



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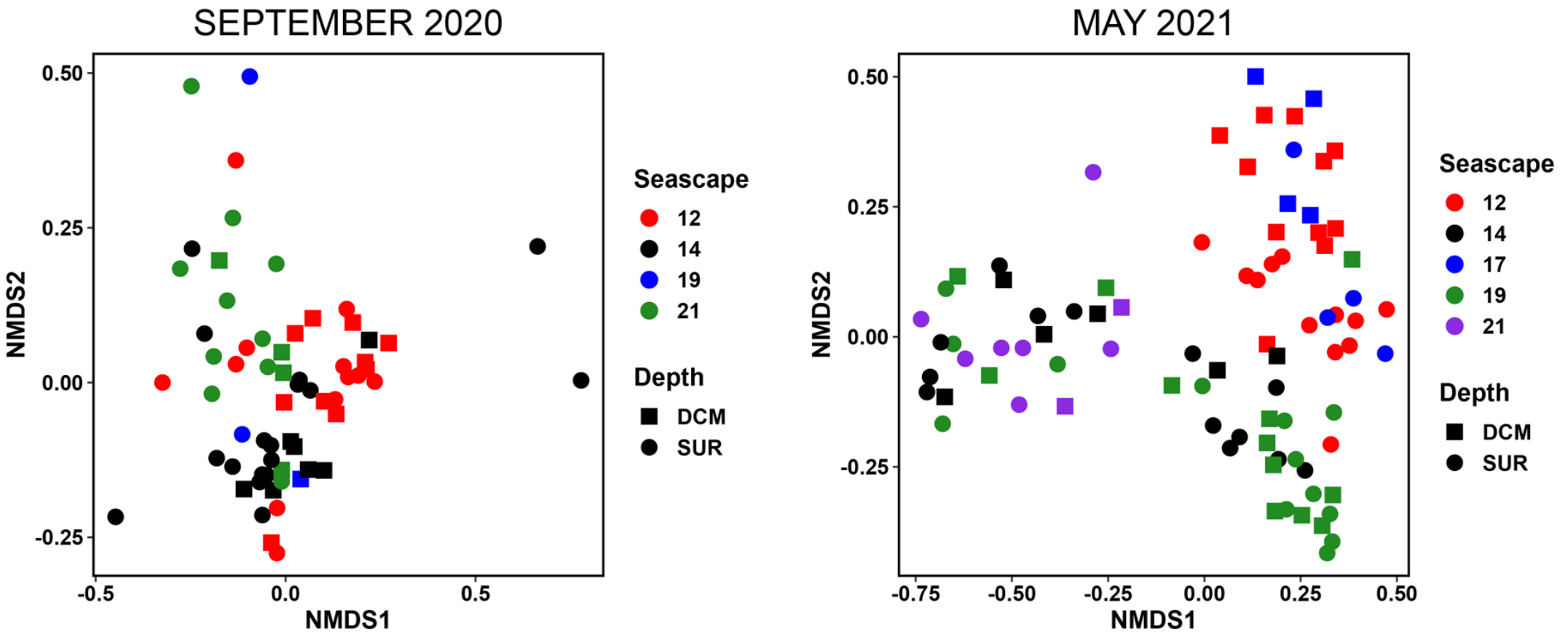
eDNA derived phytoplankton communities and Seascapes**



**Kavanaugh et al., 2014: https://doi.org/10.1016/j.pocean.2013.10.013

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Summary

- Autonomous sensors are powerful tools for collecting in situ data on phytoplankton community composition
  - High temporal & spatial frequency observations
  - Extended deployment durations (up to 6 months) with high sample capacity
- NWFSC has extensive data for the Pacific Northwest & U.S. West Coast
- Early collaborative efforts using ocean color heritage sensor data show promise for advancing PACE applications
- Please reach out!

Acknowledgements

- MBARI: Jim Birch, Roman Marin III, Brent Roman, Nadia Allaf
- UW APL: John Mickett, Nick Michel-Hart, Kevin Zack, Keith Magness, Robert Daniels, Jennie Mowatt, Liesl Danyluk, Nathan Hills, Ali Jones
- NOAA: Brian Bill, Deana Crouser, Alexis Fischer
- NOAA NCCOS Monitoring and Event Response for Harmful Algal Blooms Program
- NOAA IOOS Ocean Technology Transfer Program