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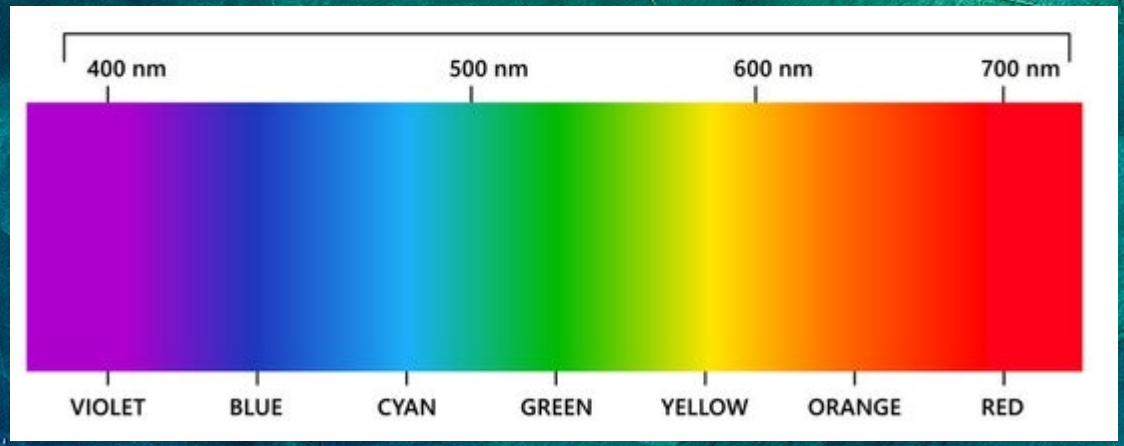
Seeing the Unseen: Tracking Copepods from Space with Ocean Color Remote Sensing

Copepod remote sensing: Potential Application on Right whales

Rebekah Shunmugapandi
Bigelow Laboratory of Ocean Sciences, East Boothbay, Maine, USA.
Email: rshunmugapandi@bigelow.org

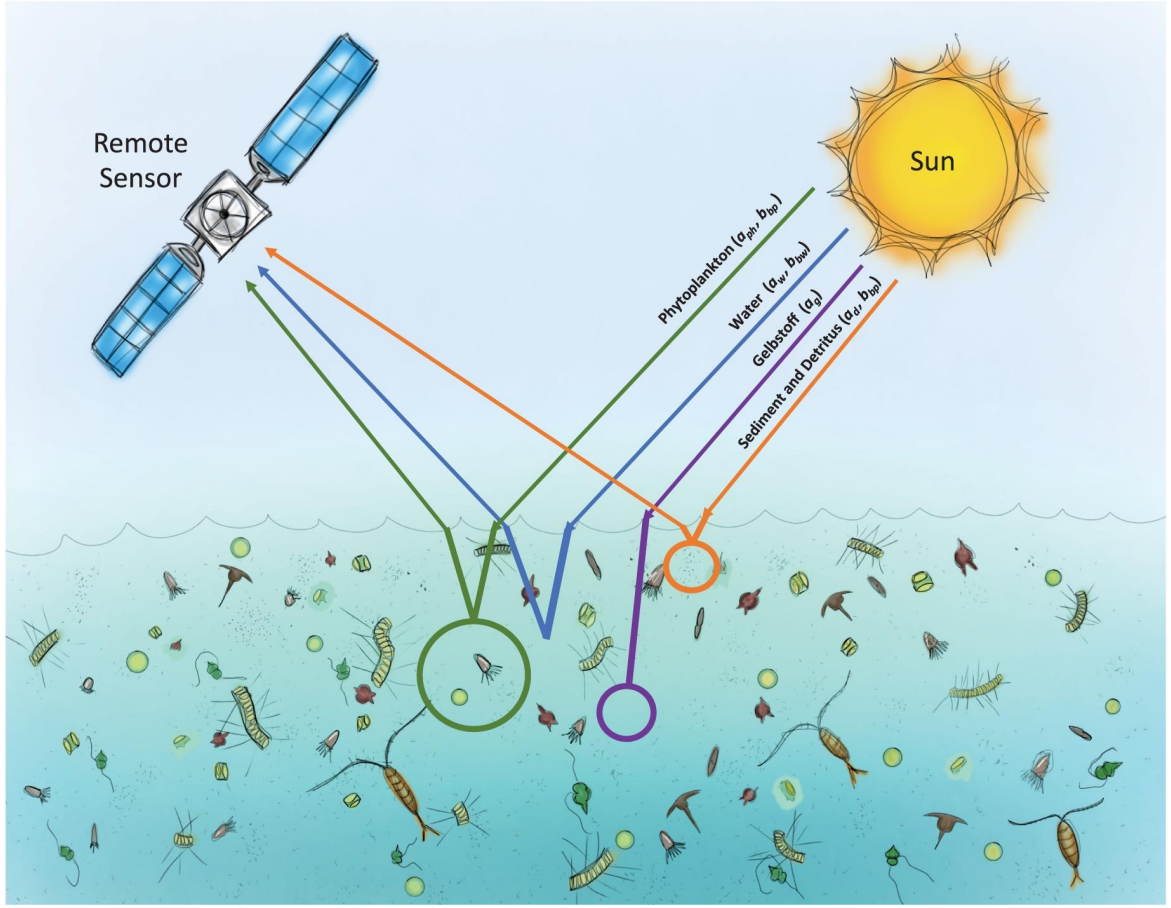


Ocean color



Source: NASA ocean color Gallery

Ocean color remote sensing



Menden-Deuer et al. (2021)

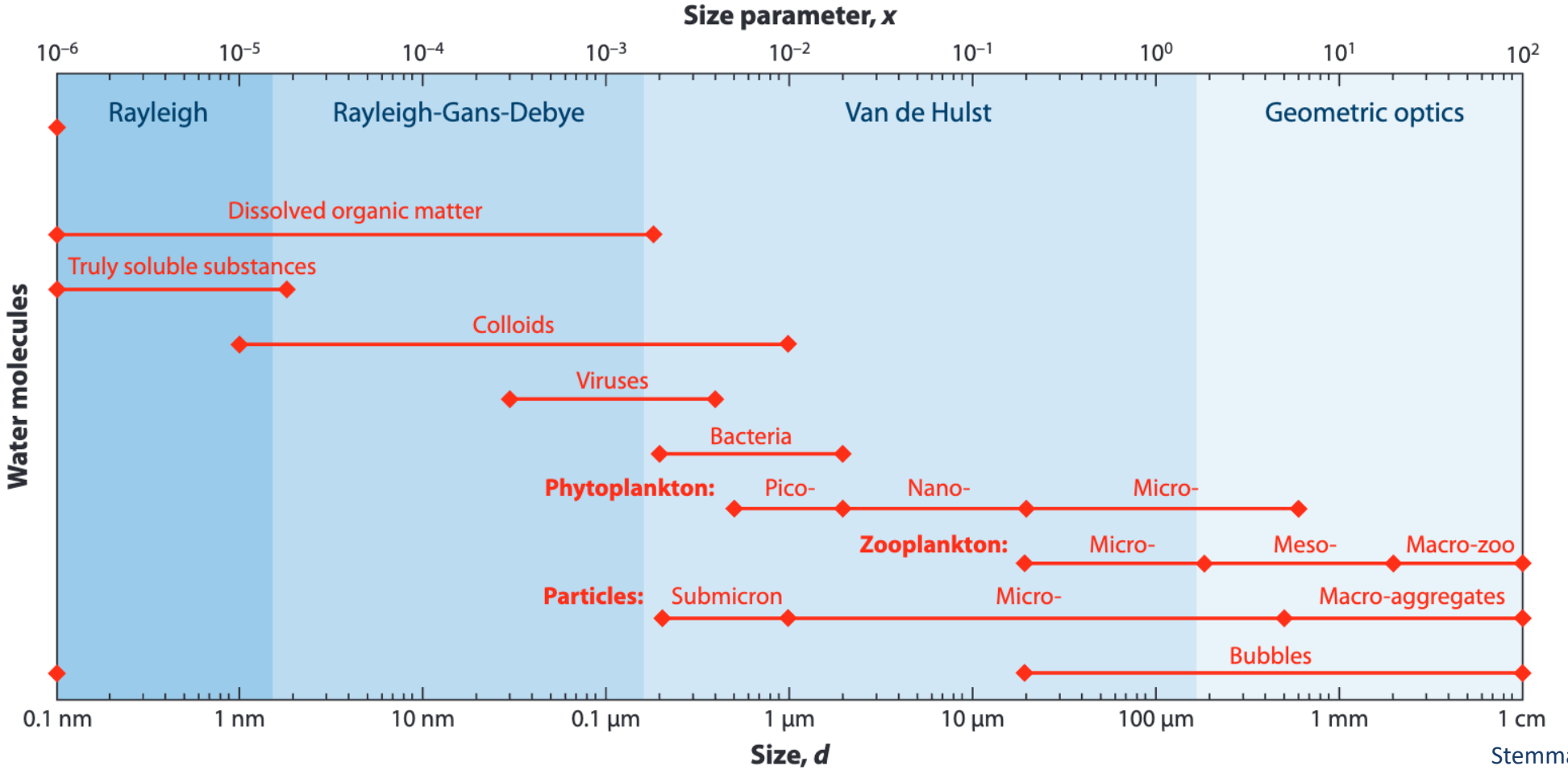
Materials that contribute to Ocean color:

Optically Significant Constituents (OSCs)

- Water
- Phytoplankton
- CDOM (Color Dissolved Organic Matter)
- Suspended sediments

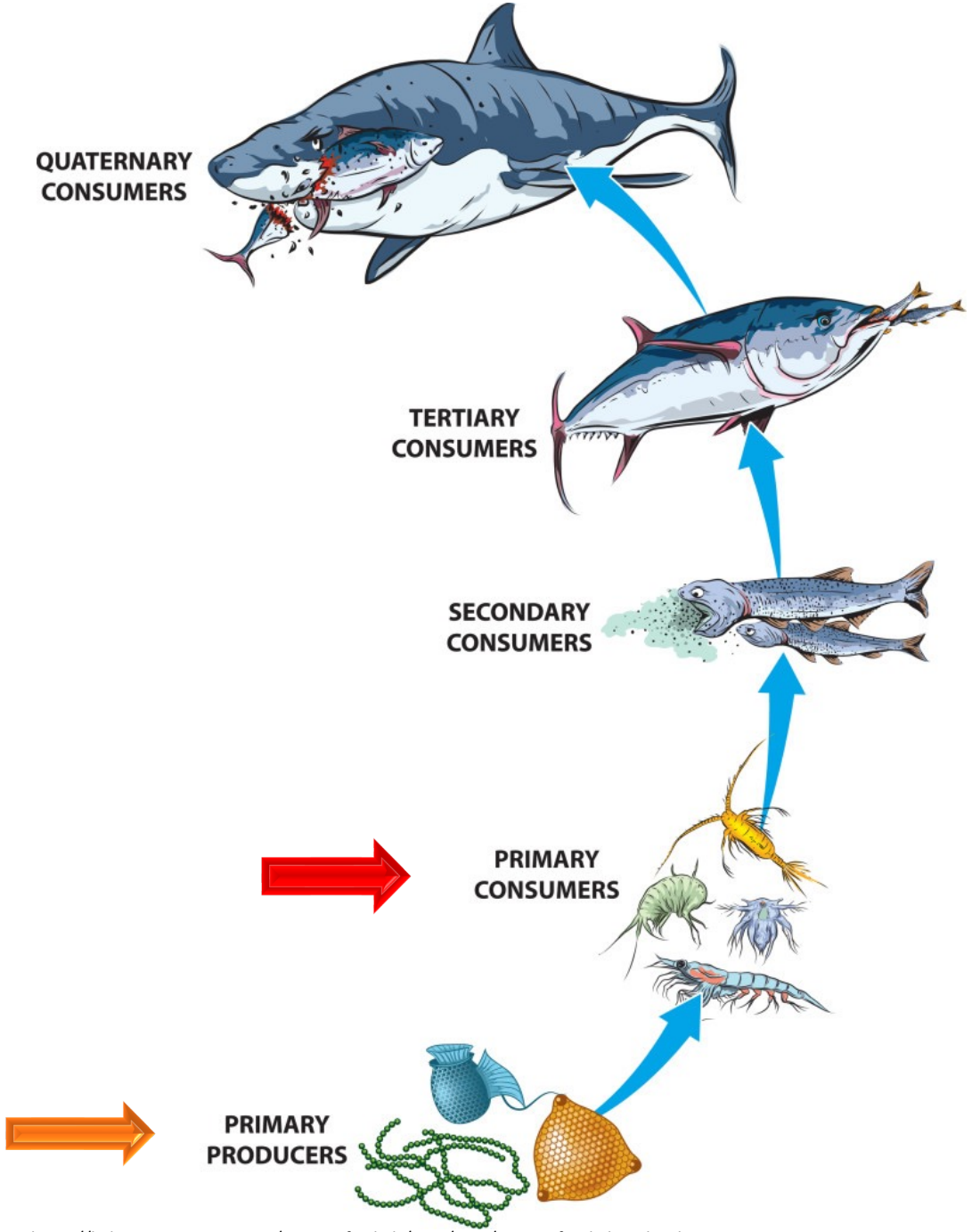
} Size of these Materials

Sizes of Optically Significant Constituents (OSCs)

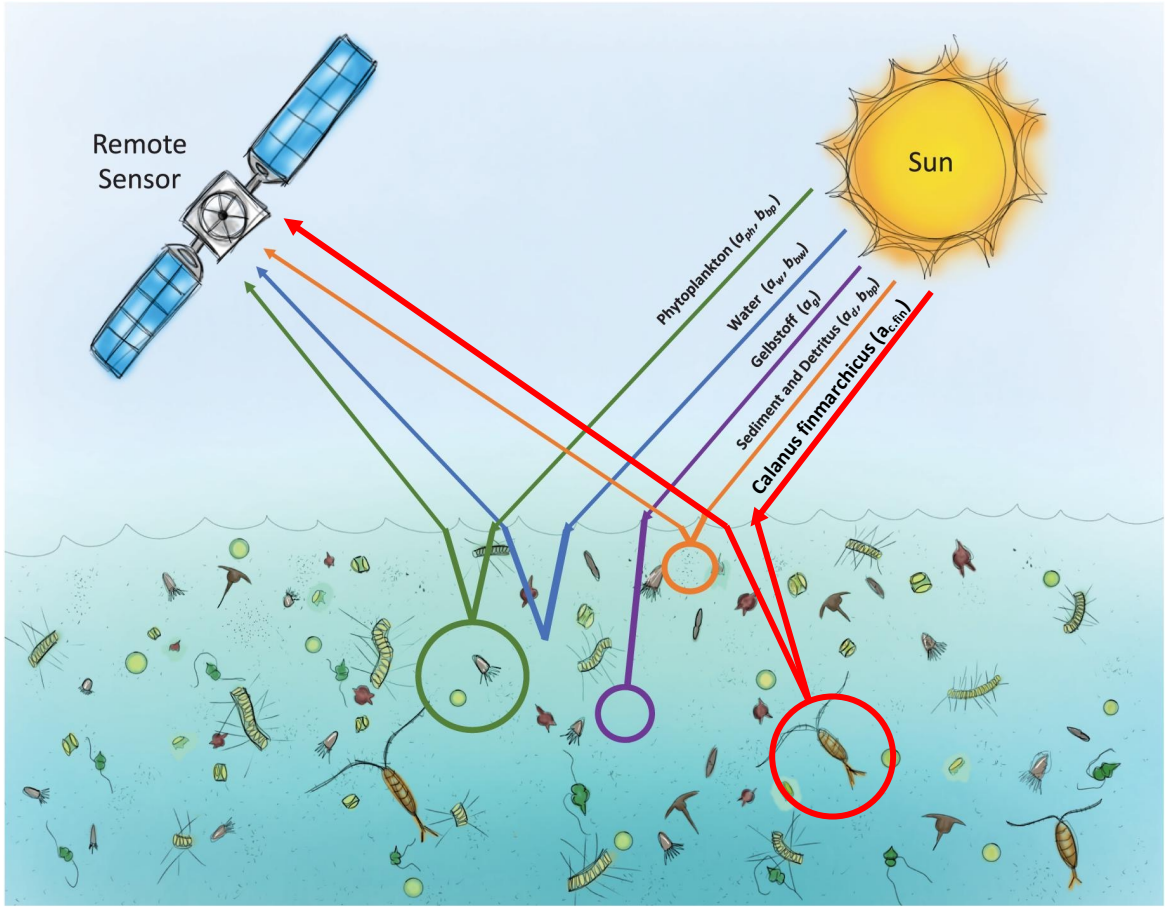


Stemmann& Boss (2012)

Zooplankton Remote sensing



Source: https://kidspressmagazine.com/science-for-kids/misc/misc/marine-food-chain.html

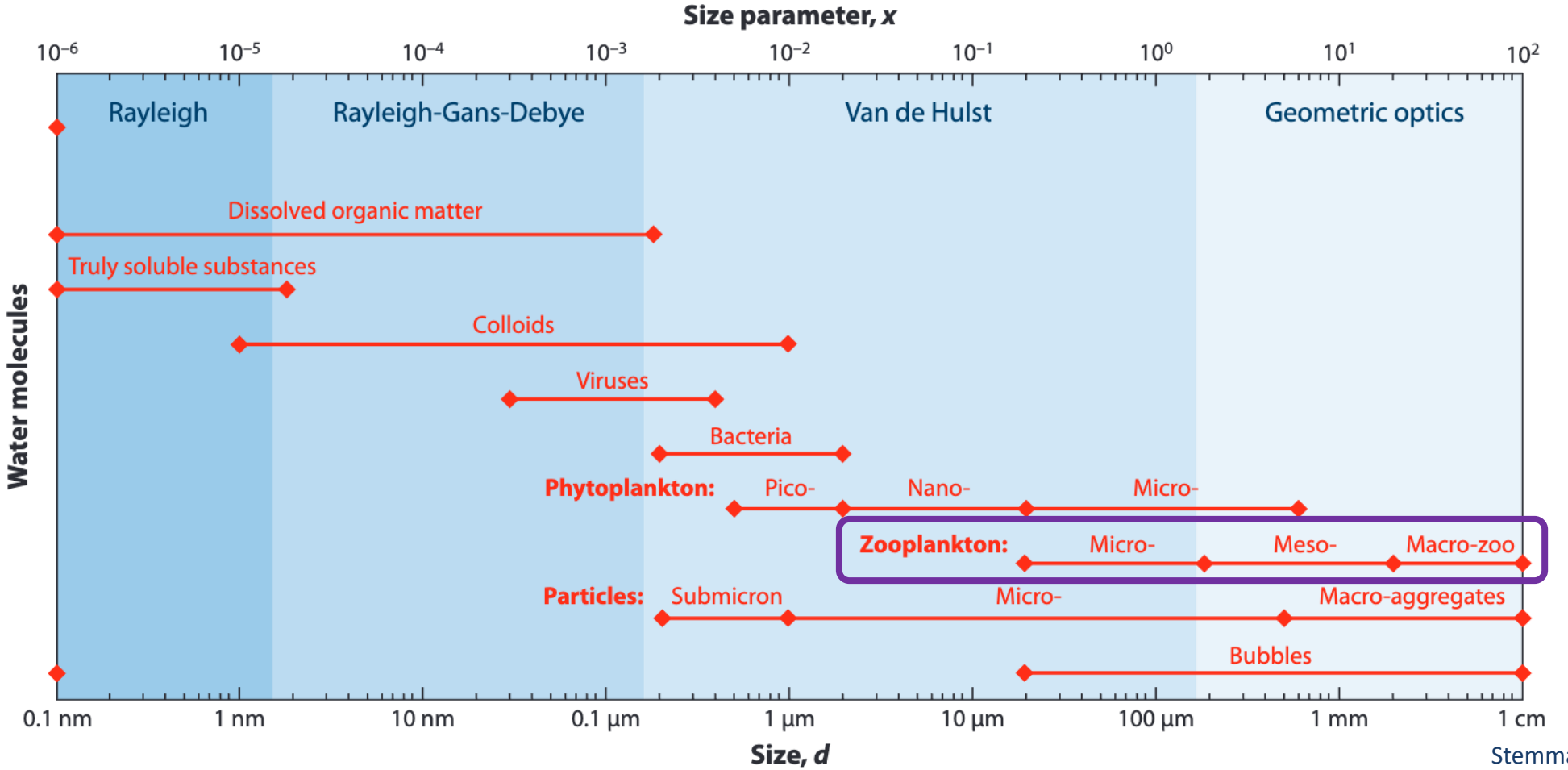


Modified from Menden-Deuer et al. (2021)



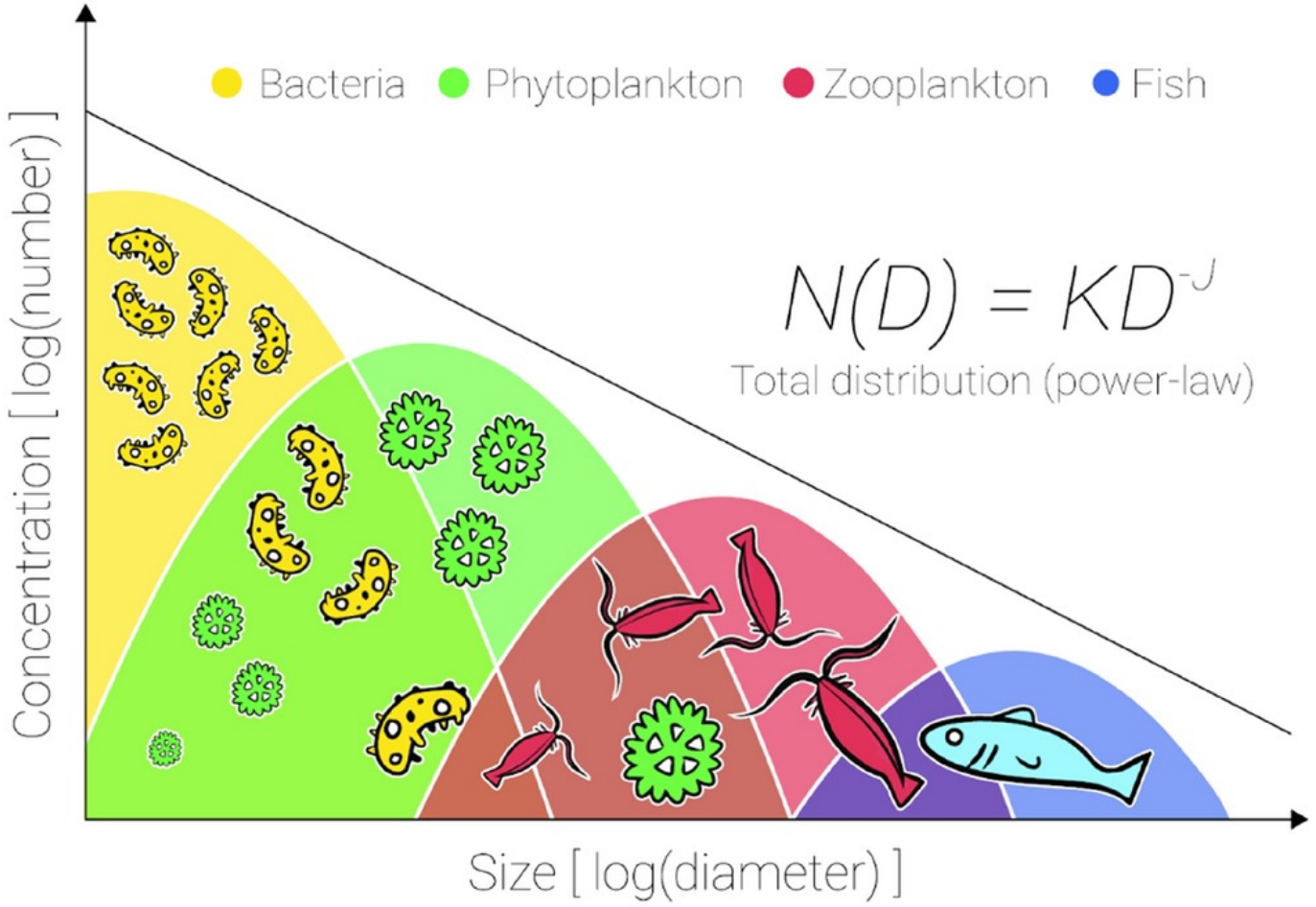
Calanus finmarchicus

Sizes of Zooplankton



Stemmann& Boss (2012)

Influence of large particles on ocean color

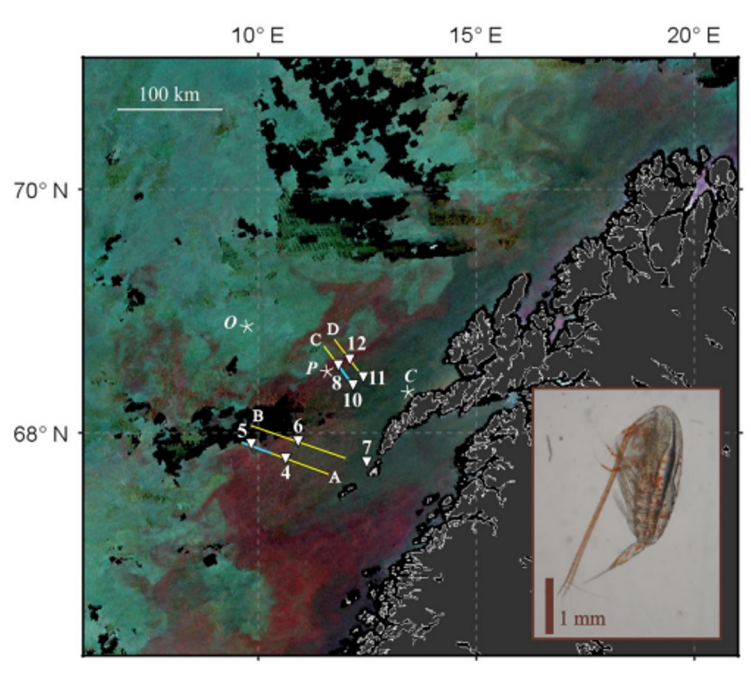


Davies et al (2021)

Detecting copepods from space

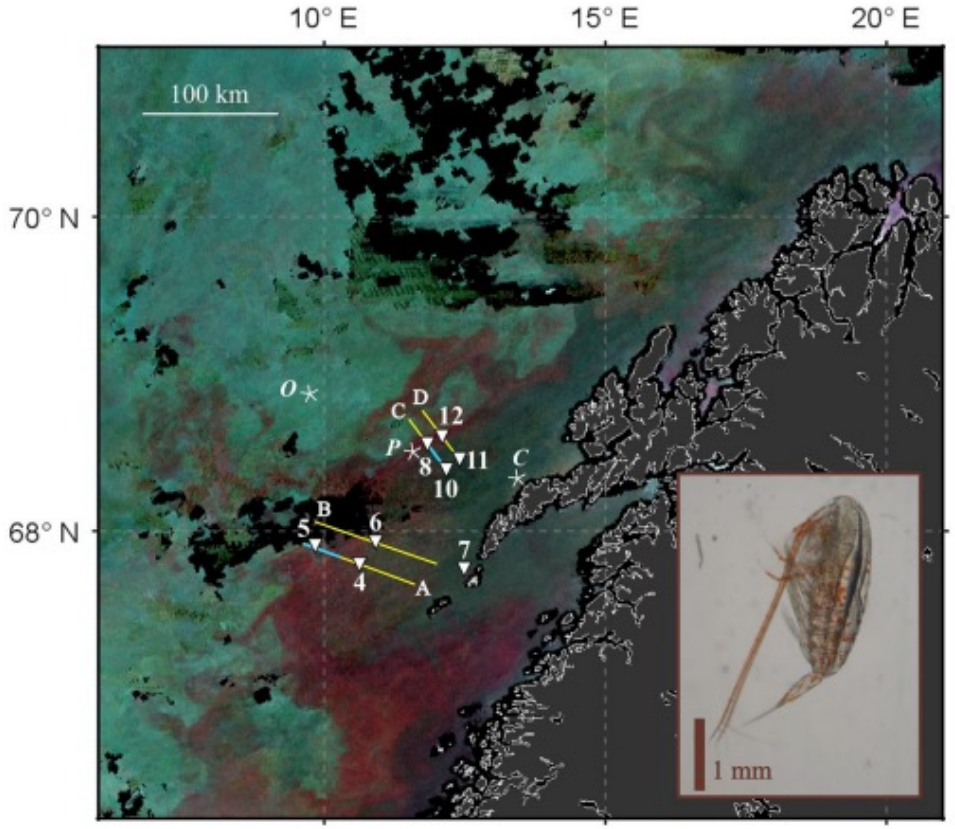






(Basedow et al., 2019)

Remote sensing of Zooplankton swarms



enhanced RGB (eRGB) satellite image shows the high abundances of C. finmarchicus in the off Norwegian Coast. (Basedow et al., 2019)

SCIENTIFIC REPORTS

OPEN

Remote sensing of zooplankton swarms

Sünnje L. Basedow[1], David McKee[2], Ina Lefering[2], Astthor Gislason[3], Malin Daase[1], Emilia Trudnowska[4], Einar Skarstad Egeland[5], Marvin Choquet[5] & Stig Falk-Petersen[1,6]

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Zooplankton provide the key link between primary production and higher levels of the marine food web and they play an important role in mediating carbon sequestration in the ocean. All commercially harvested fish species depend on zooplankton populations. However, spatio-temporal distributions of zooplankton are notoriously difficult to quantify from ships. We know that zooplankton can form large aggregations that visibly change the color of the sea, but the scale and mechanisms producing these features are poorly known. Here we show that large surface patches (>1000 km²) of the red colored copepod *Calanus finmarchicus* can be identified from satellite observations of ocean color. Such observations provide the most comprehensive view of the distribution of a zooplankton species to date, and alter our understanding of the behavior of this key zooplankton species. Moreover, our findings suggest that high concentrations of astaxanthin-rich zooplankton can degrade the performance of standard blue-green reflectance ratio algorithms in operational use for retrieving chlorophyll concentrations from ocean color remote sensing.

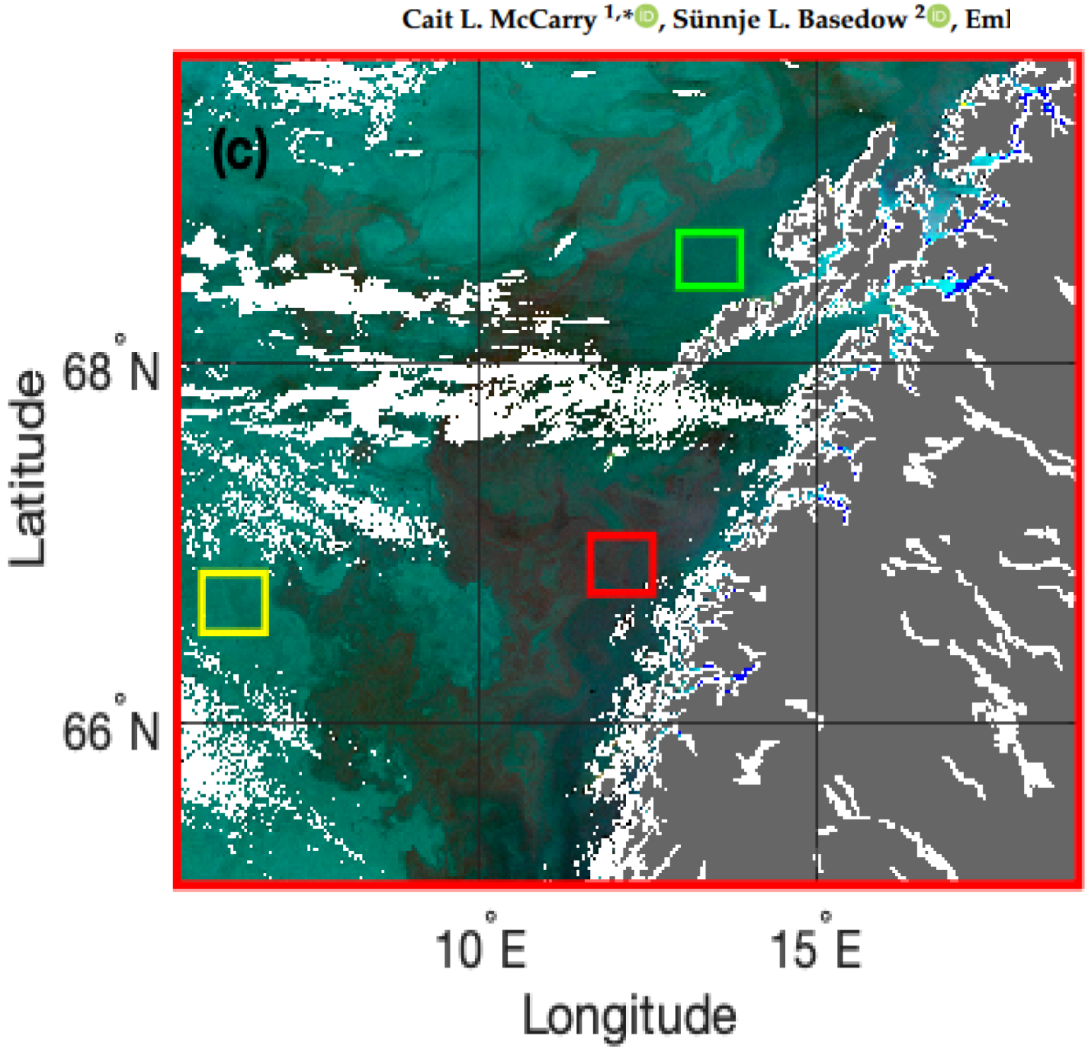
remote sensing

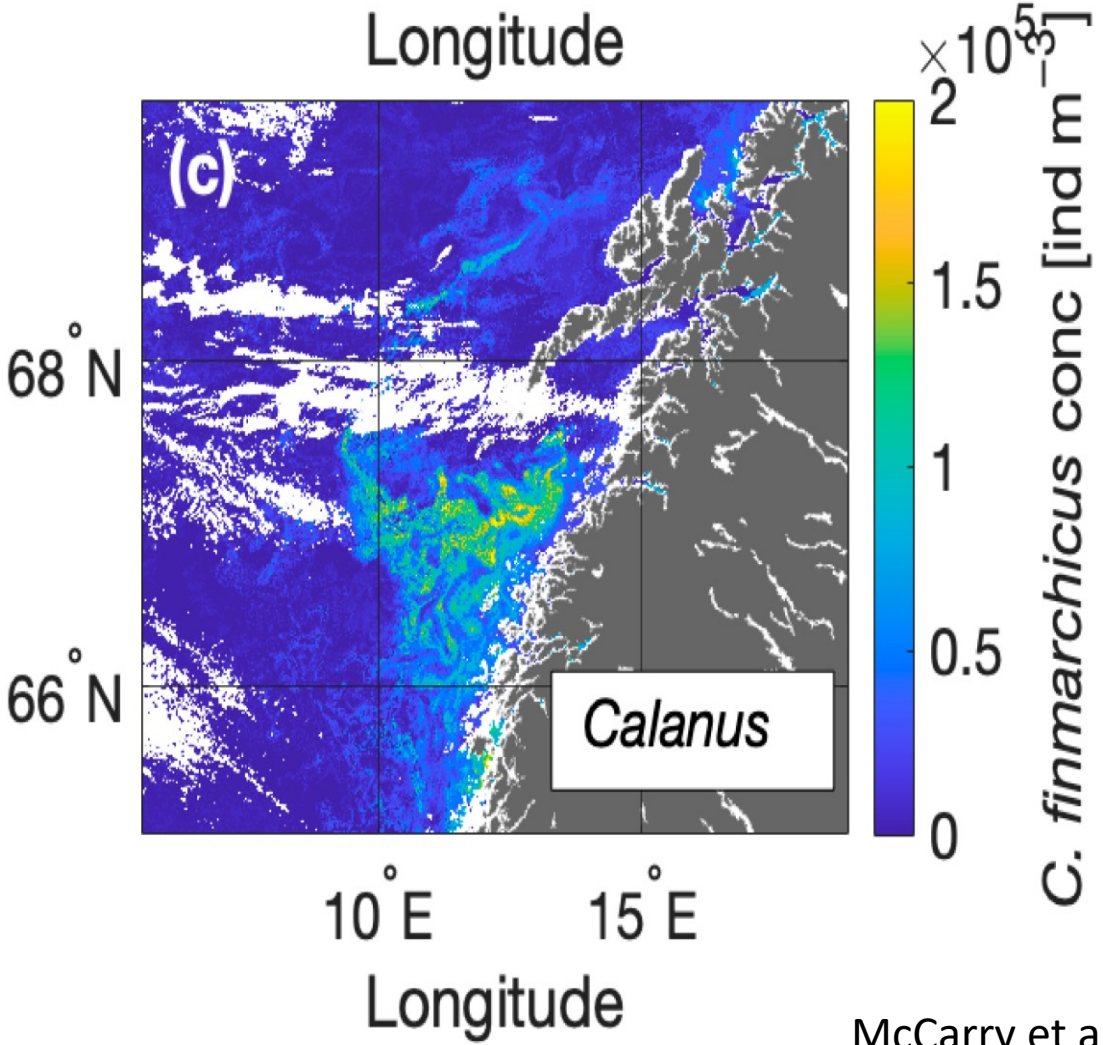
MDPI

Article

Estimating Surface Concentrations of *Calanus finmarchicus* Using Standardised Satellite-Derived Enhanced RGB Imagery

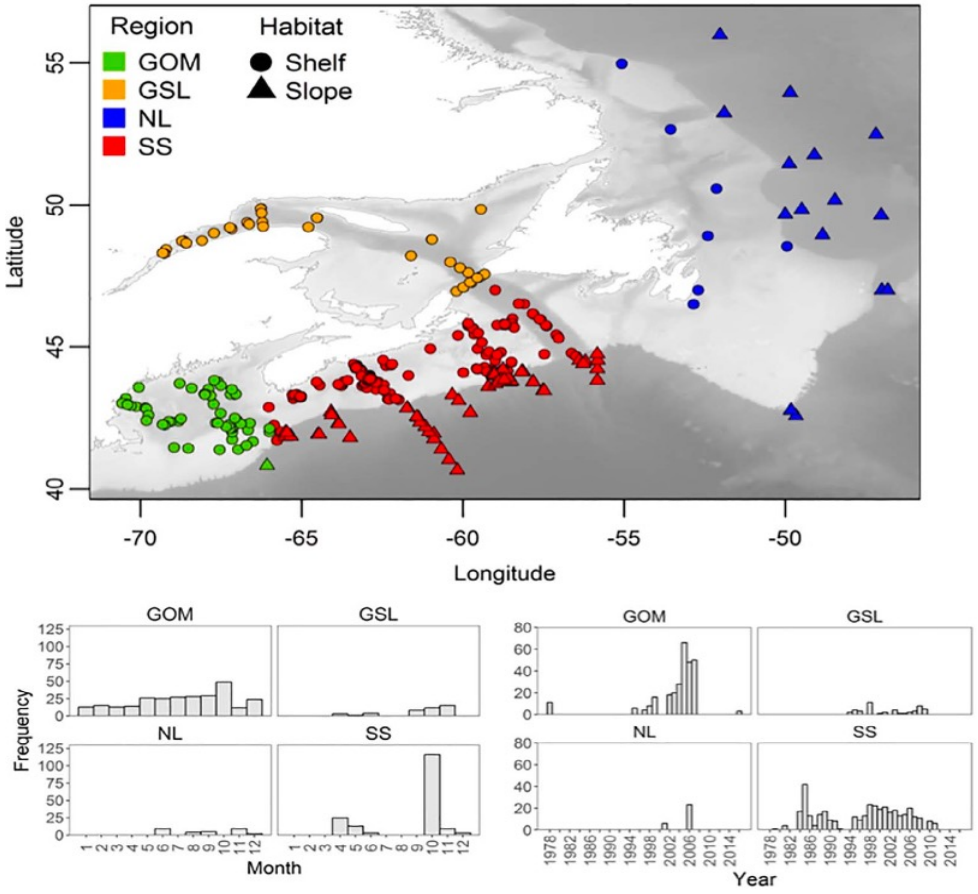
Cait L. McCarry [1,*], Sünnje L. Basedow [2], Eml



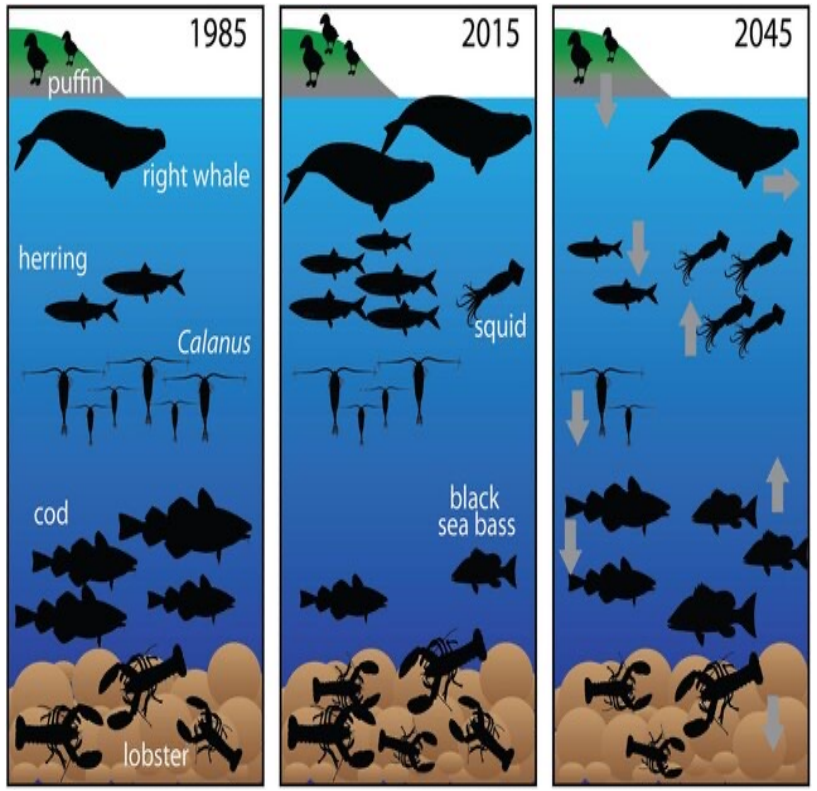


McCarry et al. (2023)

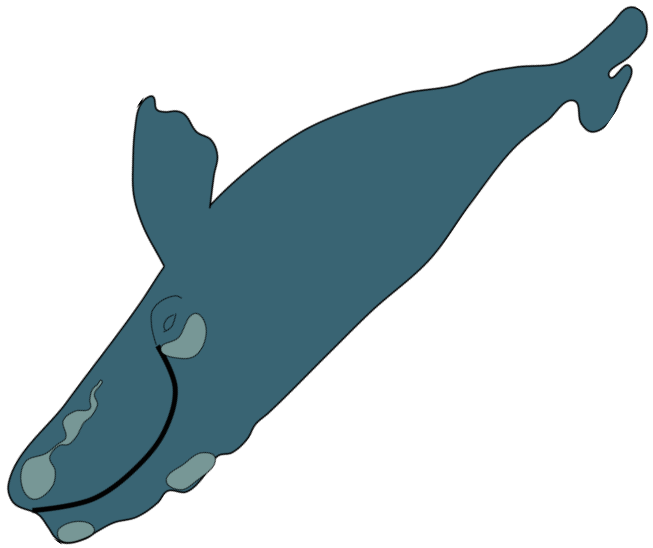
Why the Gulf of Maine (GoM)?

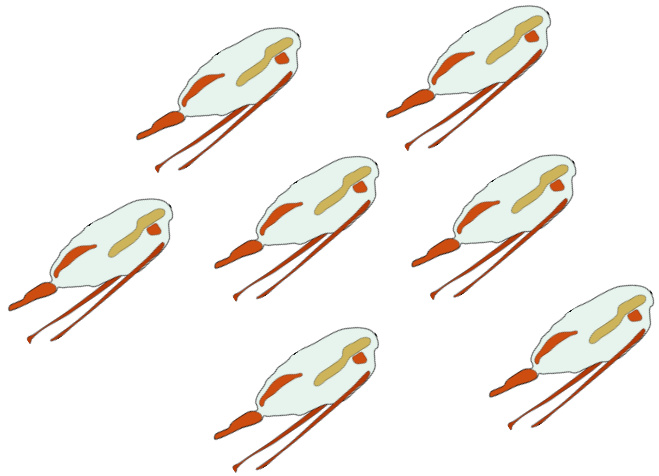


Krumhansl et al., (2018)



Pershing et al., (2021)

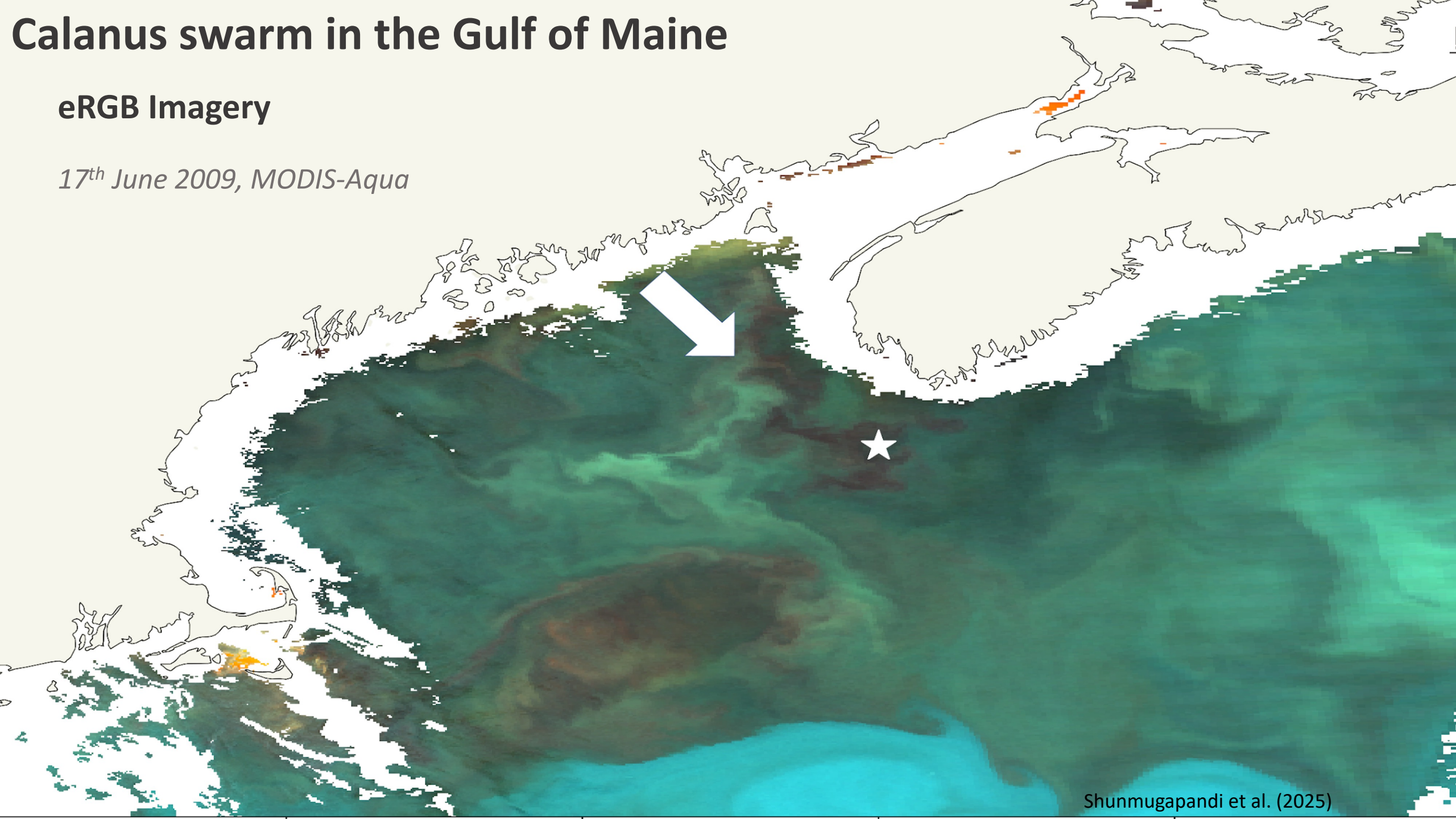




Calanus swarm in the Gulf of Maine

eRGB Imagery

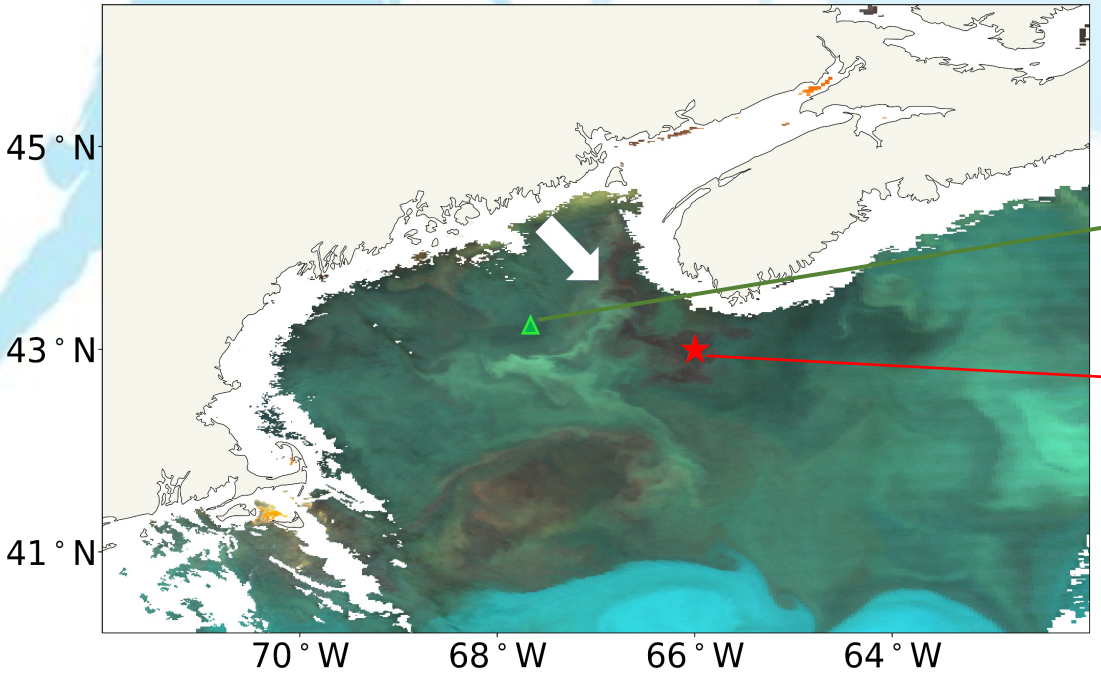
17th June 2009, MODIS-Aqua

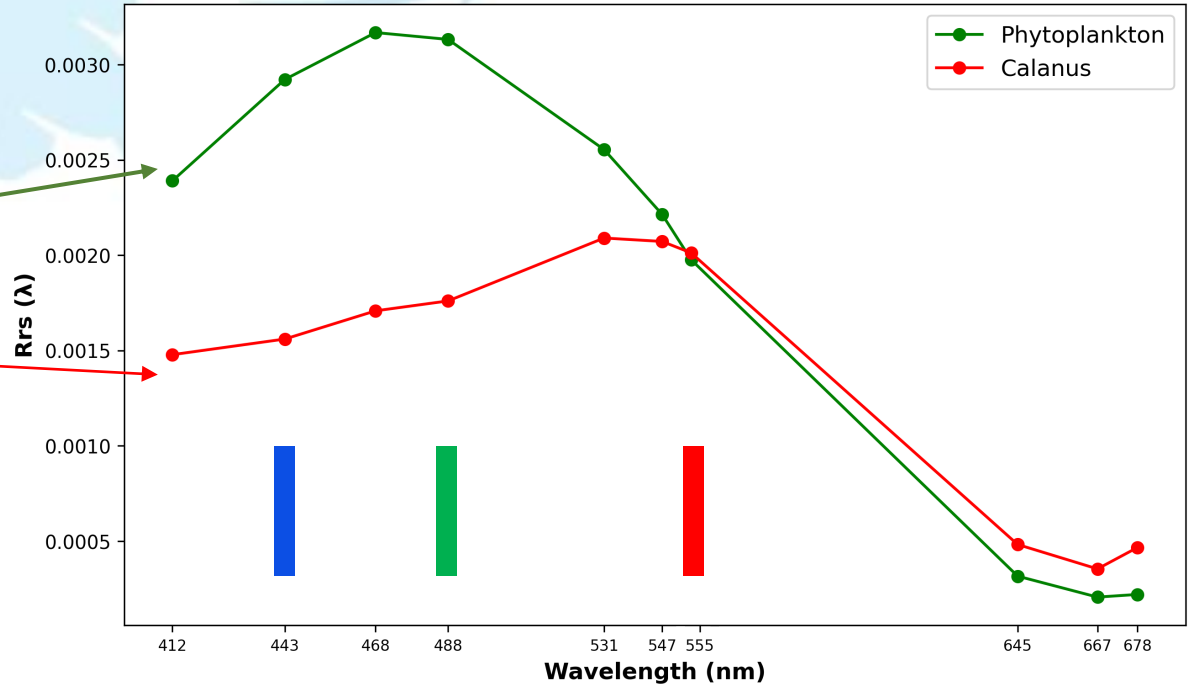


Shunmugapandi et al. (2025)

Spectral signature of Calanus patch

MODIS Aqua L2 enhanced RGB image from 17th June 2009

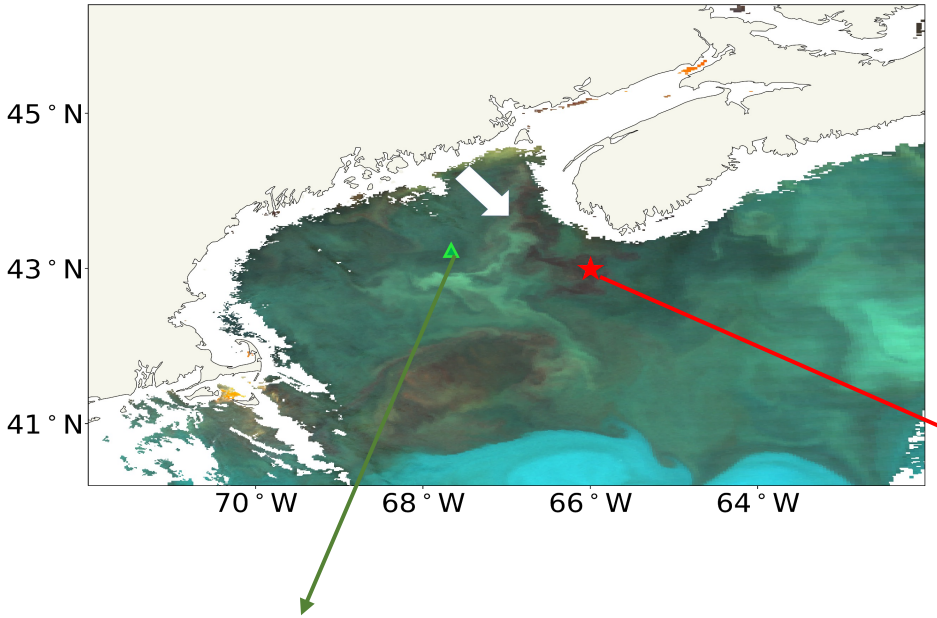




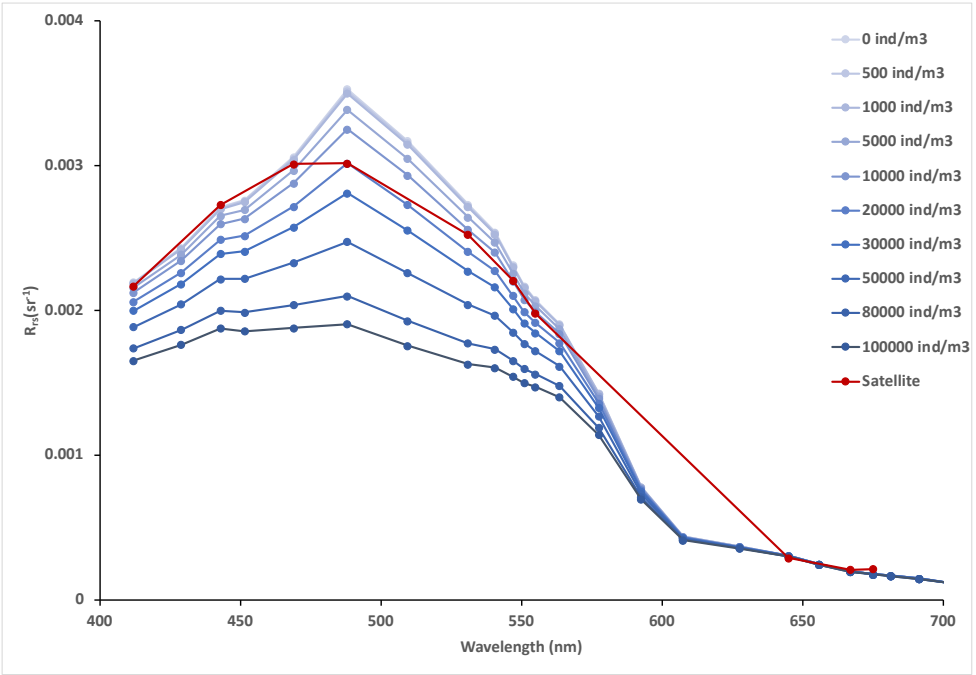
★ High concentrations of in situ Calanus (from surface CPR data)

Shunmugapandi et al. (2025)

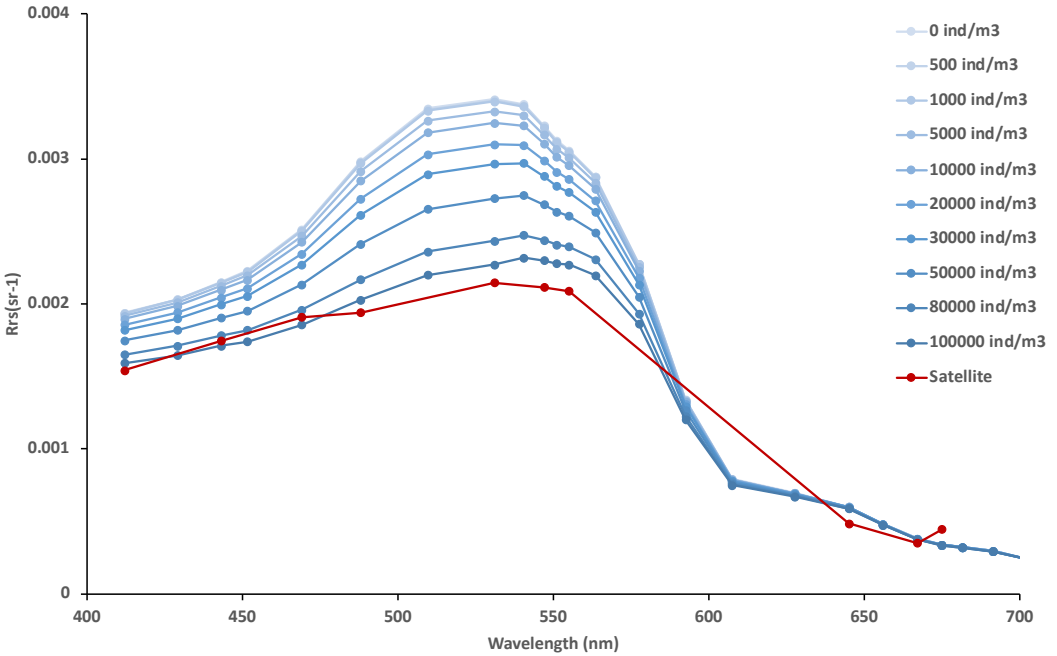
Remote sensing reflectance



Outside patch



Inside patch



Bio-optical model

Mass-specific inherent optical property (SIOP)

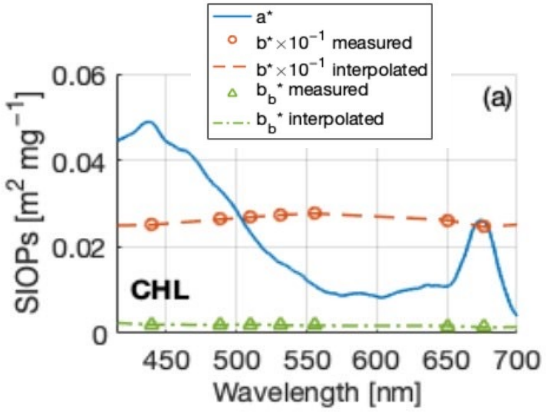
$$a = a_{ww} + a_{ph} + a_{CDCCM} + a_{MSS}$$

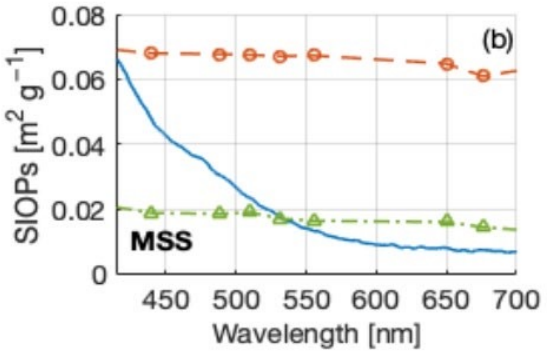
$$a = a_{ww} + a^*_{ph}[CHL] + a^*_{CDCCM}[CDOM] + a^*_{MSS}[MSS] + a^*_{cal}[CAL]$$

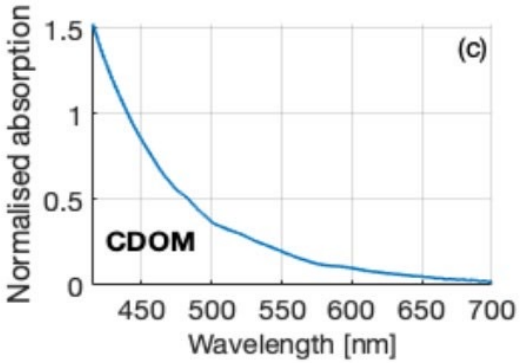
$$b = b_{ww} + b^*_{ph}[CHL] + b^*_{MSS}[MSS]$$

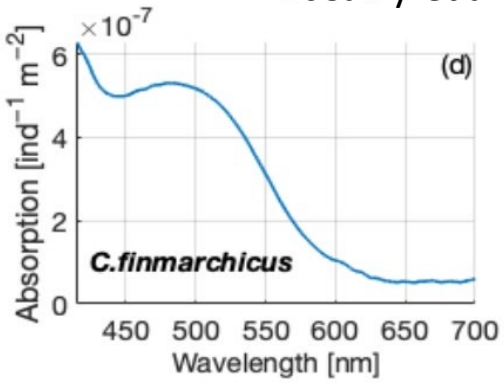
OSM concentration

$$b_b = b_{bww} + b^*_{b\ ph}[CHL] + b^*_{b\ MSS}[MSS]$$



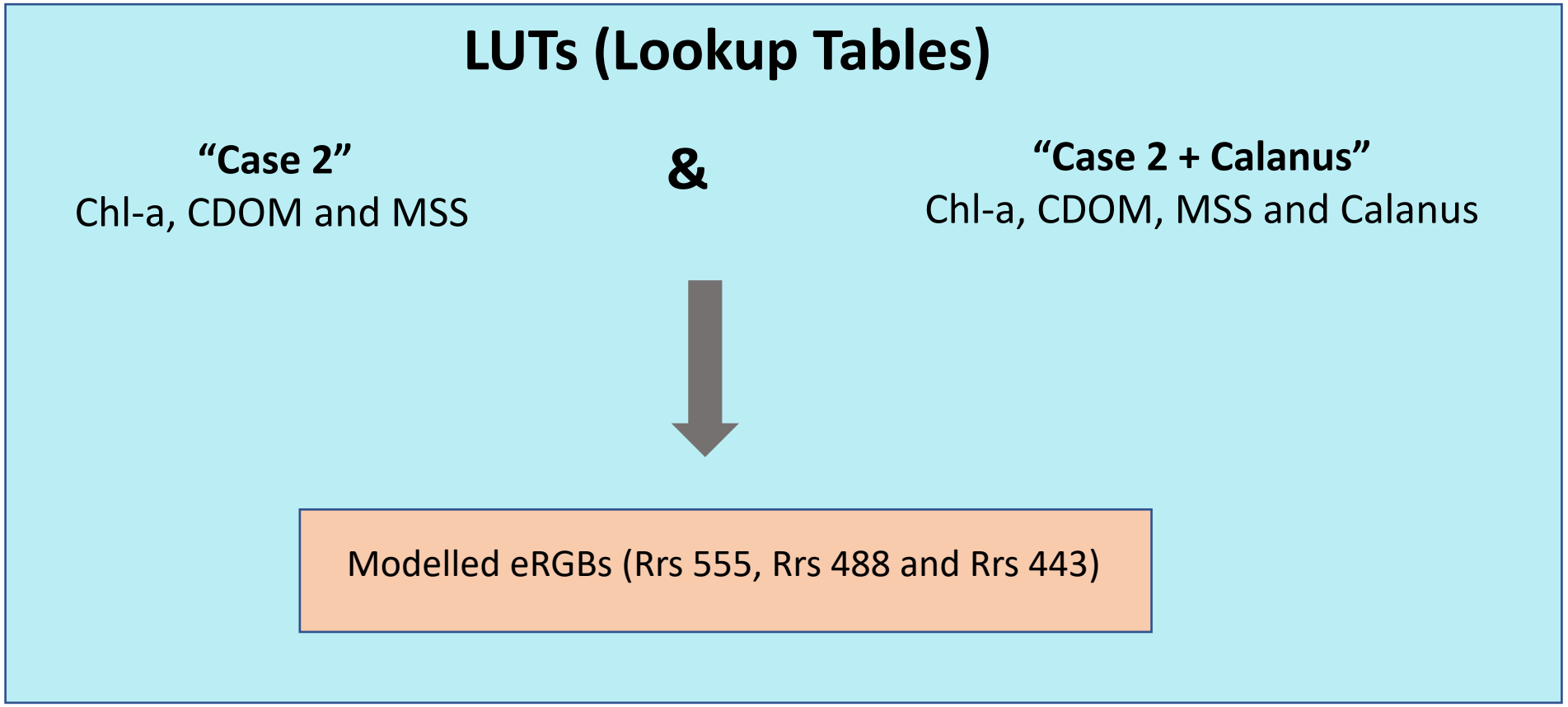




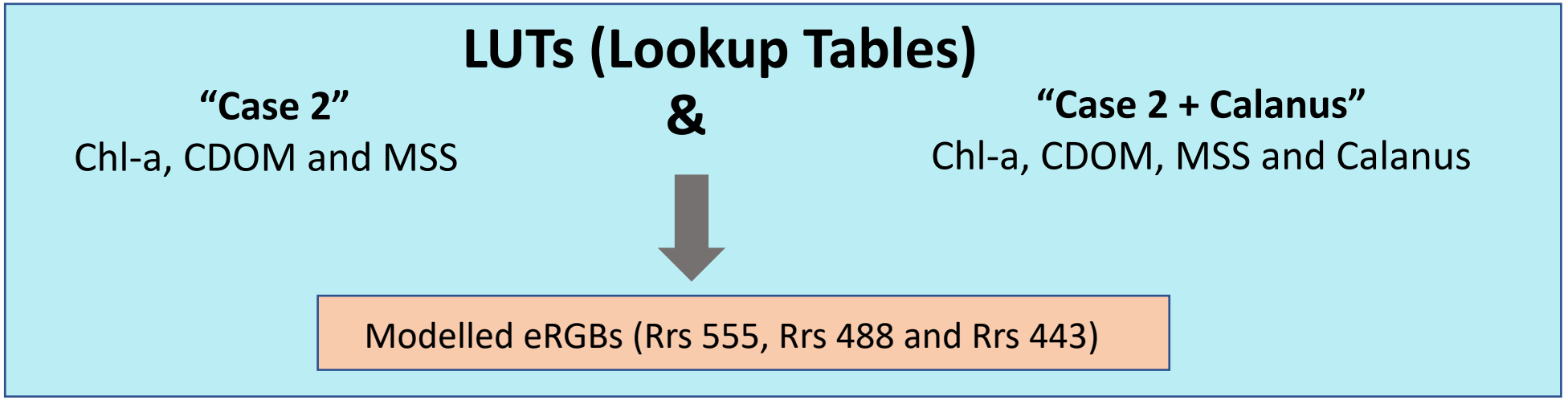


McCarry et al (2023)

eRGB color matching method: Ocean color anomaly detection



eRGB color matching method: Ocean color anomaly detection

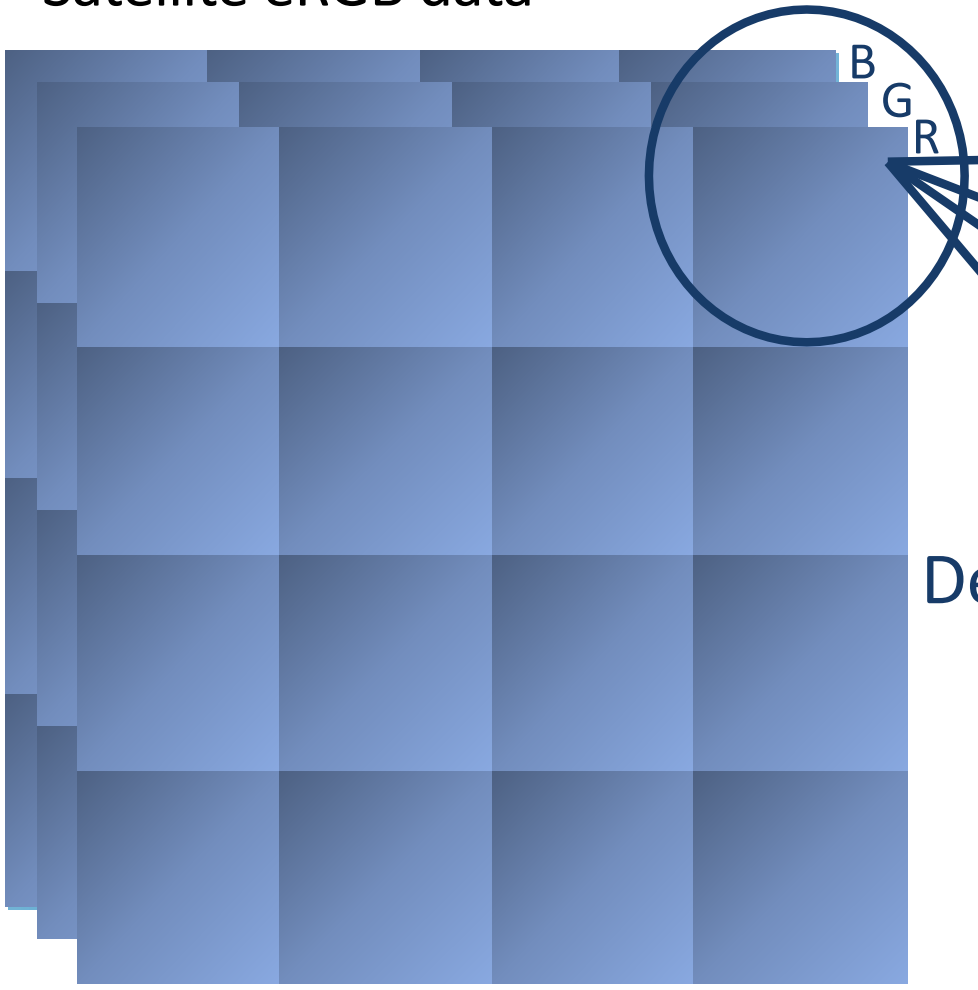


- Use the DeltaE (ΔE) anomaly mapping technique of McCarry et al. (2023)
- ΔE quantifies color differences between LUT eRGBs and satellite eRGBs, where ΔE ranges from 0 – 100.
- For each pixel, the minimum ΔE value ($\Delta E^{\min}{}_{2000}$) is identified
  - The LUT entry that best matches the satellite pixel value
- A larger $\Delta E^{\min}{}_{2000}$ value suggests the bio-optical model (i.e. the LUT) does not fully explain what is being seen in the satellite pixel

  There is an optical anomaly, thus a map of $\Delta E^{\min}{}_{2000}$ can be considered as an optical anomaly map.

How it works?

Satellite eRGB data



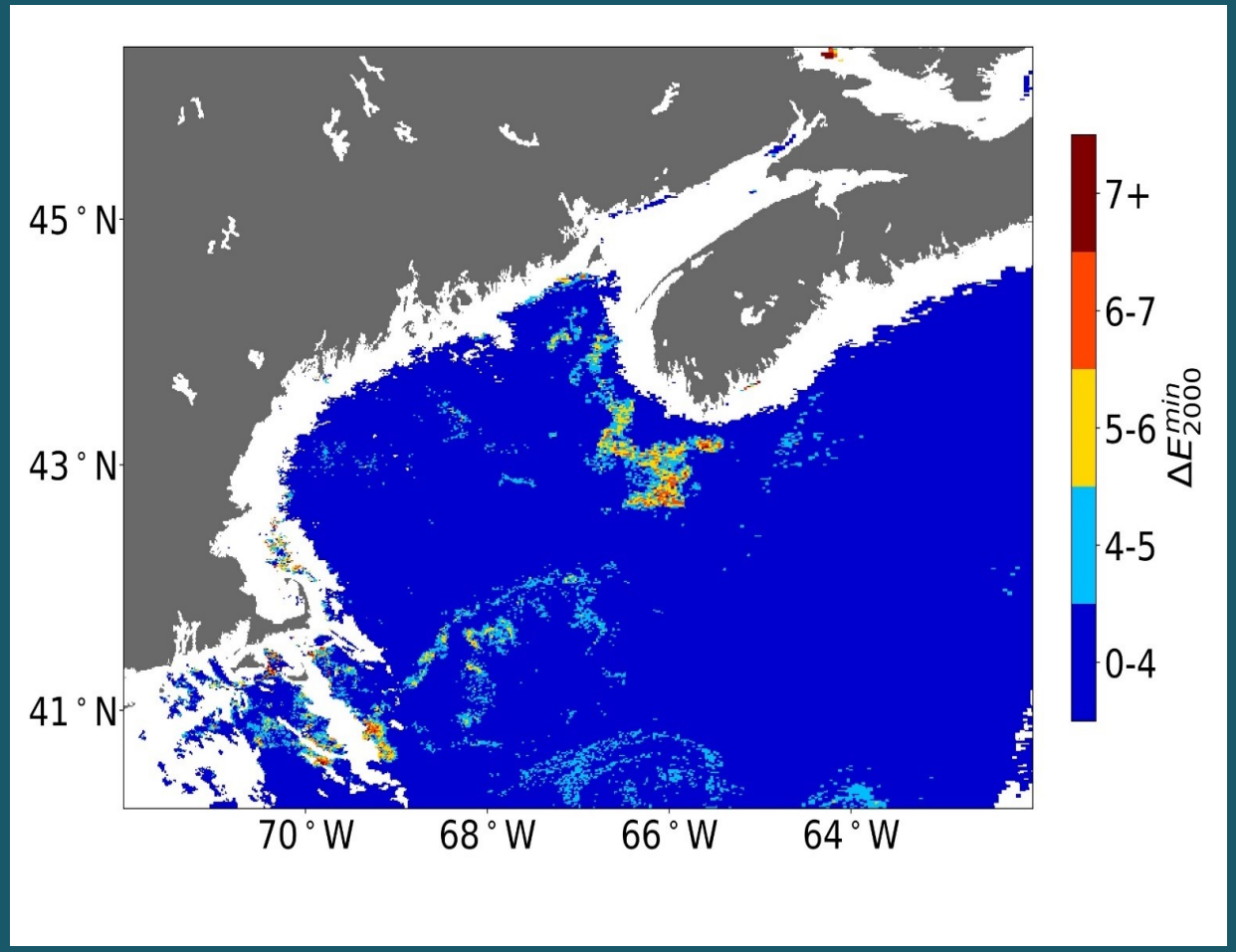
DeltaE

Look-up-table (LUT)

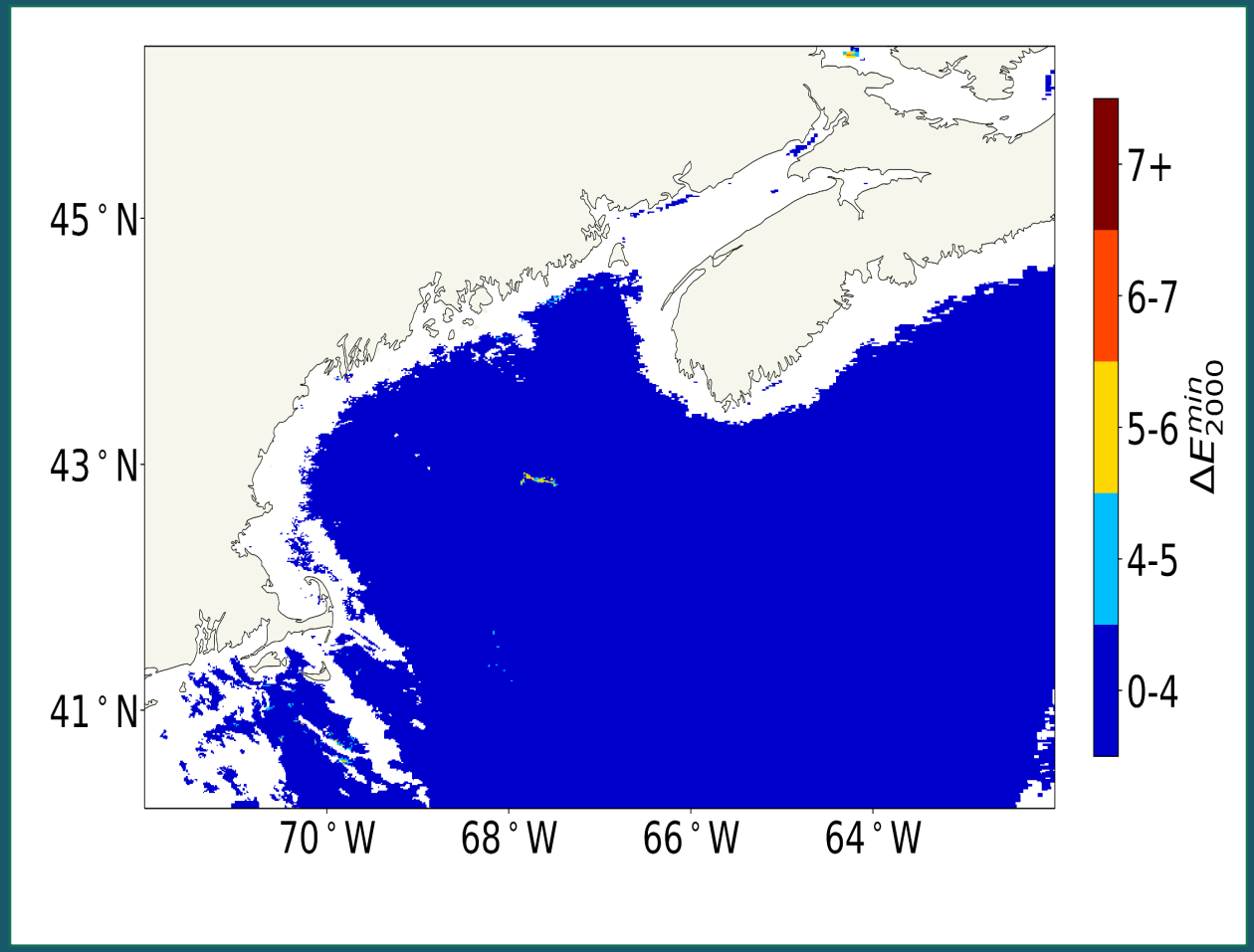
RED	GREEN	BLUE	CHL	MSS	CDOM	CAL

Ocean color anomaly detection: Threshold based approach

Case 2 anomaly map



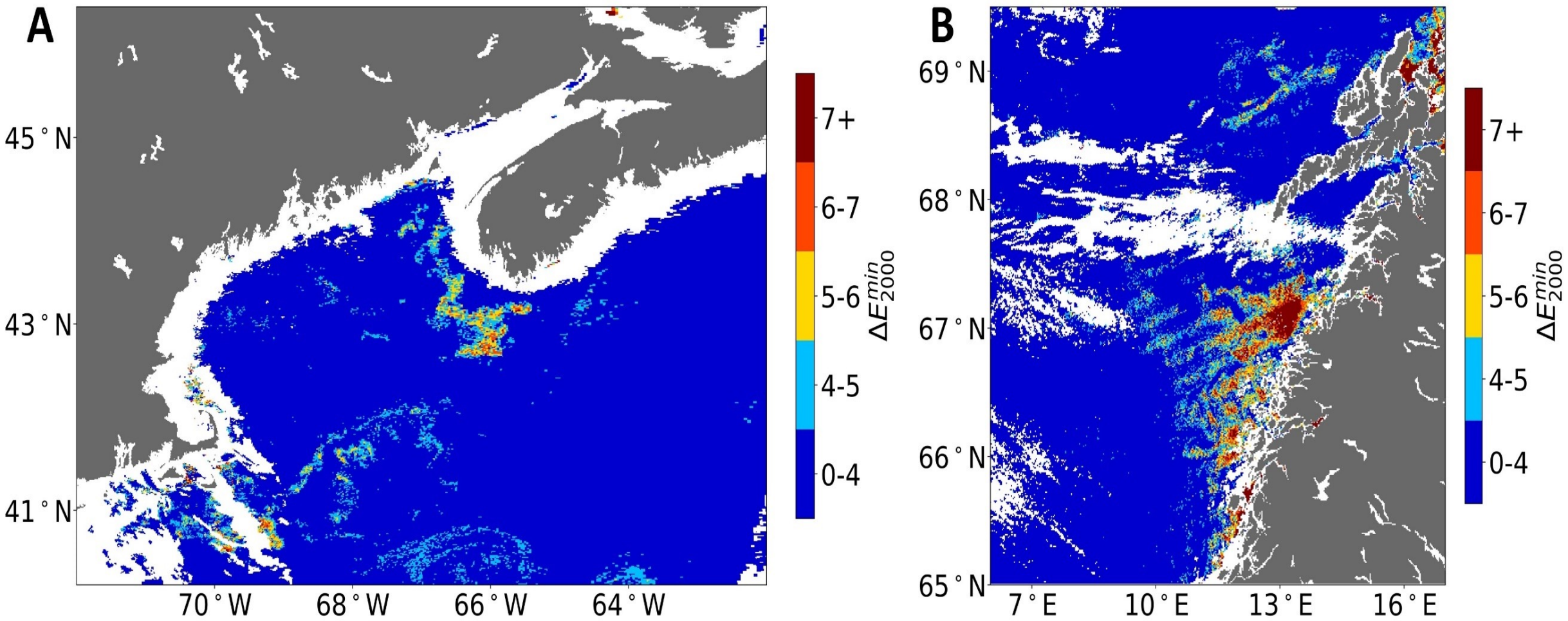
Case 2 + Calanus refined anomaly map



The refined binned ΔE_{2000}^{min} anomaly maps indicate that a Case 2 ΔE_{2000}^{min} threshold of ≥ 4 typically identifies pixels that are anomalous due to Calanus

Shunmugapandi et al. (2025)

Ocean color anomaly detection: Threshold based approach

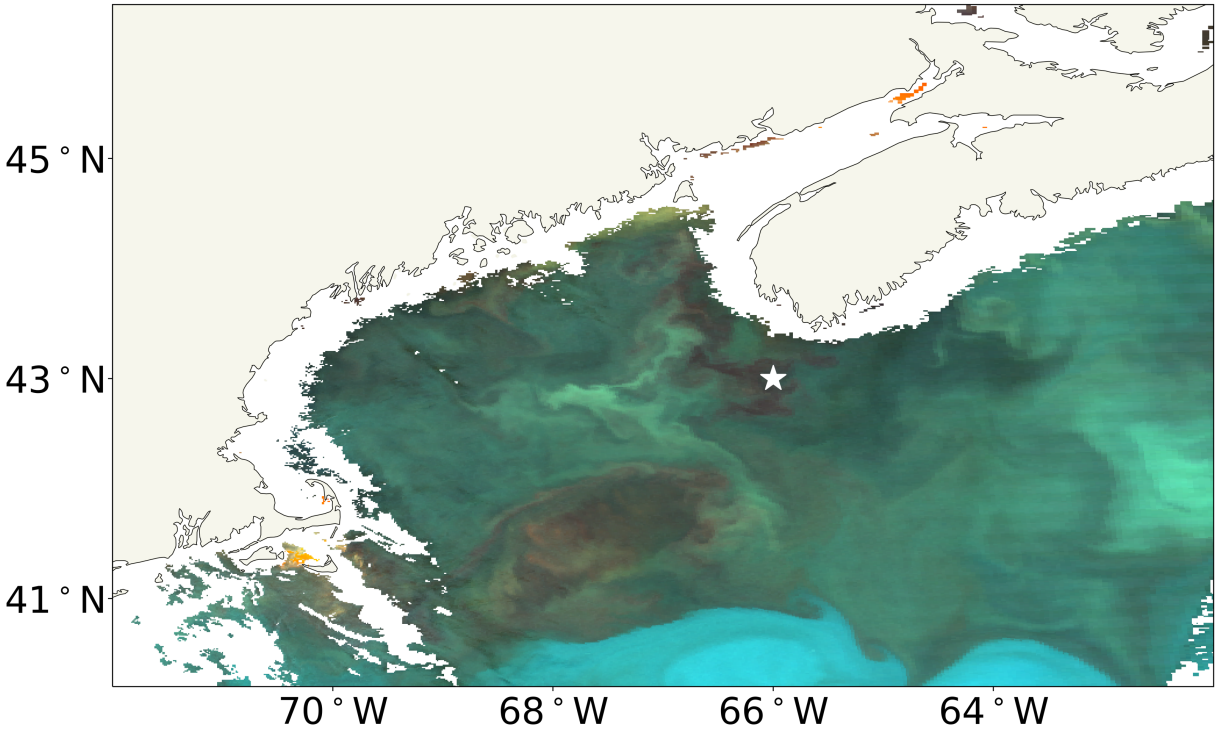


Binned ΔE_{2000}^{min} Case 2 anomaly map of (A) Gulf of Maine(B) off the coast Norway

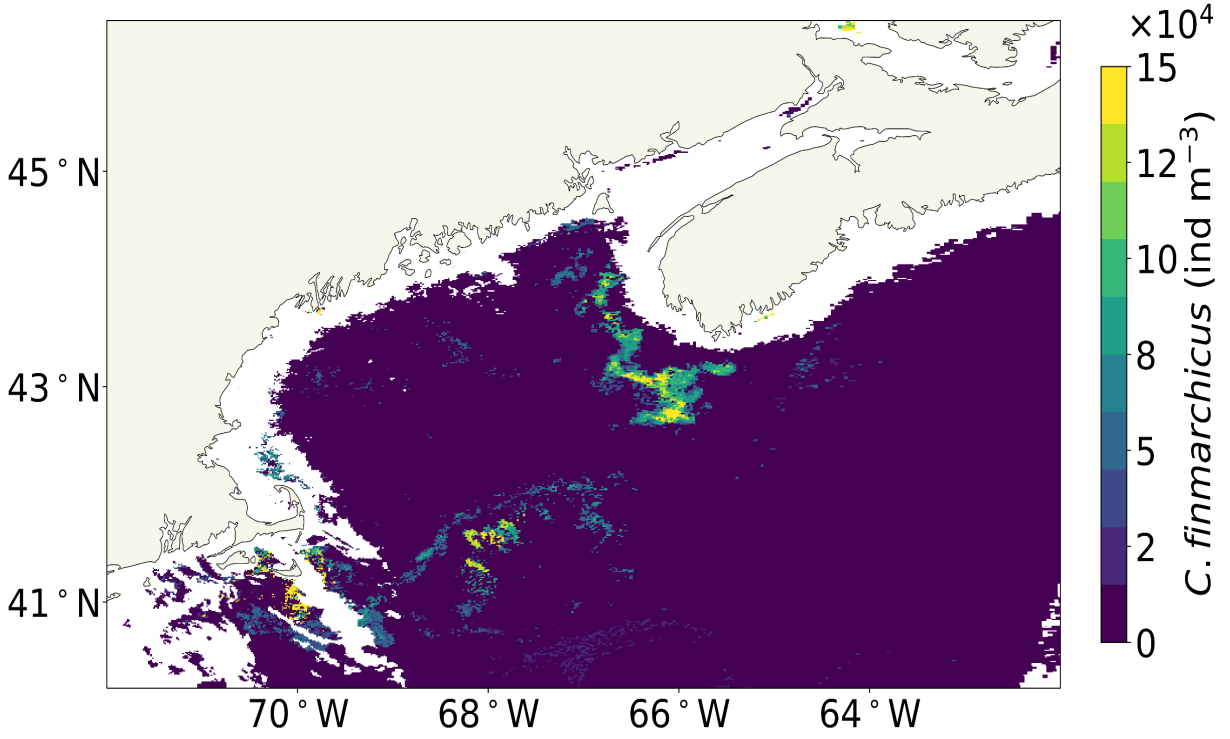
Shunmugapandi et al. (2025)

Estimated Calanus concentration

eRGB Imagery



Surface Calanus Concentration



The refined Calanus estimation method developed from McCarry et al. (2023) has been applied on the optically complex GoM waters. This is the example figures shows the eRGB imagery on the left and the estimated Calanus concentration on the right on June 17 2009.

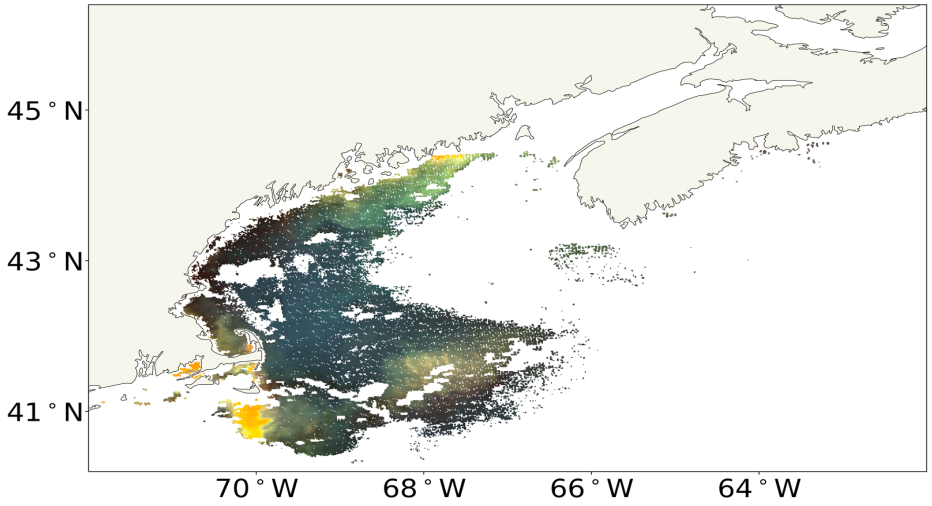
Shunmugapandi et al. (2025)

Factors affecting the Calanus estimation: Centropages misidentified as Calanus

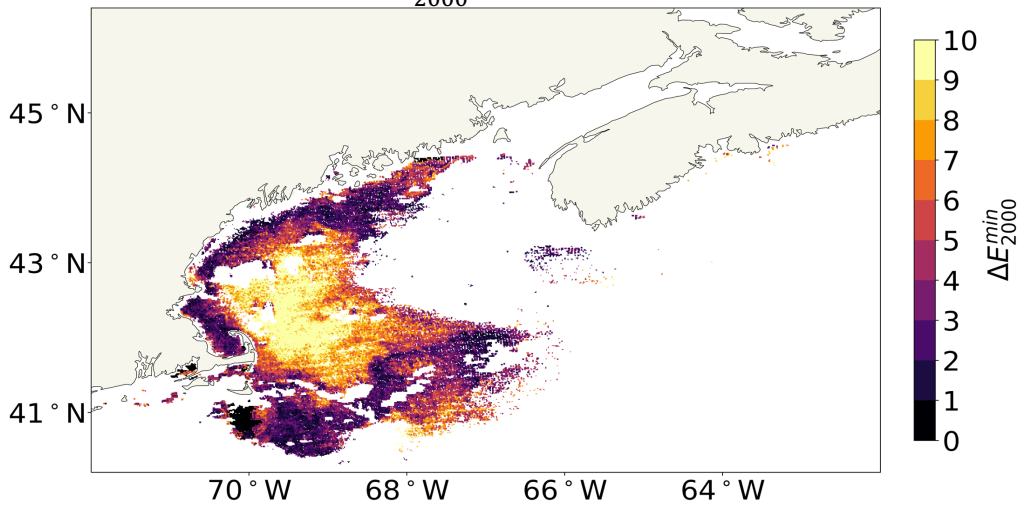
November 21, 2017

Shunmugapandi et al. (2025)

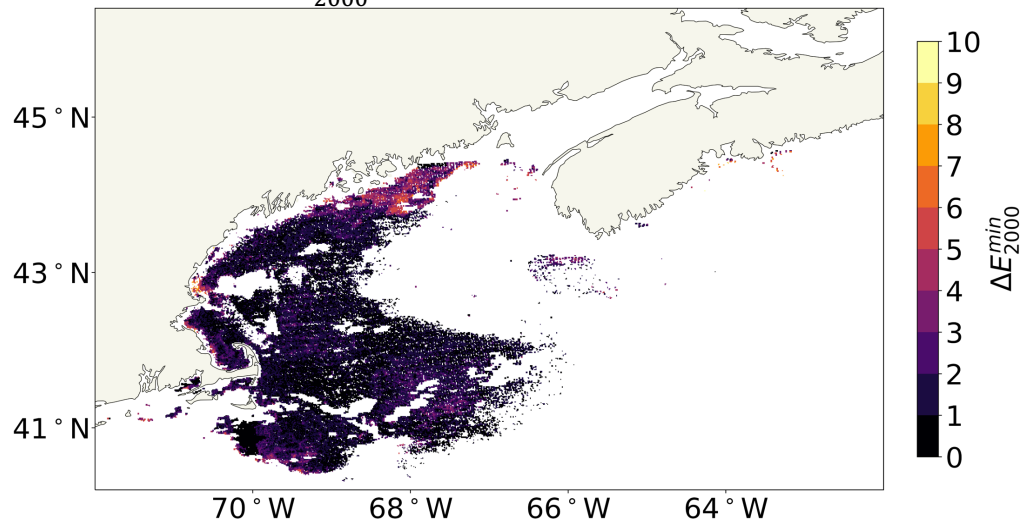
eRGB image



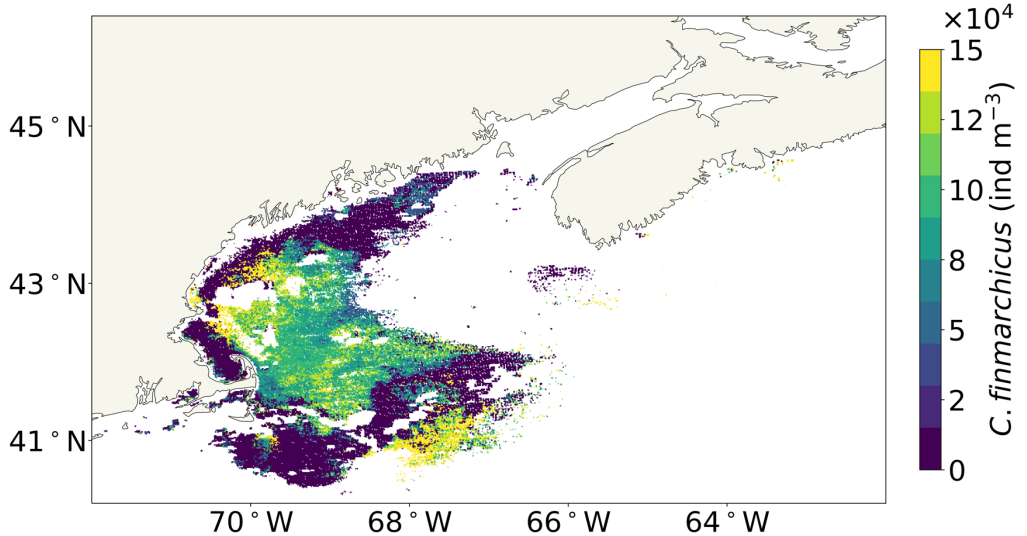
Case 2 ΔE^{min}_{2000} anomaly map



Refined ΔE^{min}_{2000} with Calanus anomaly map



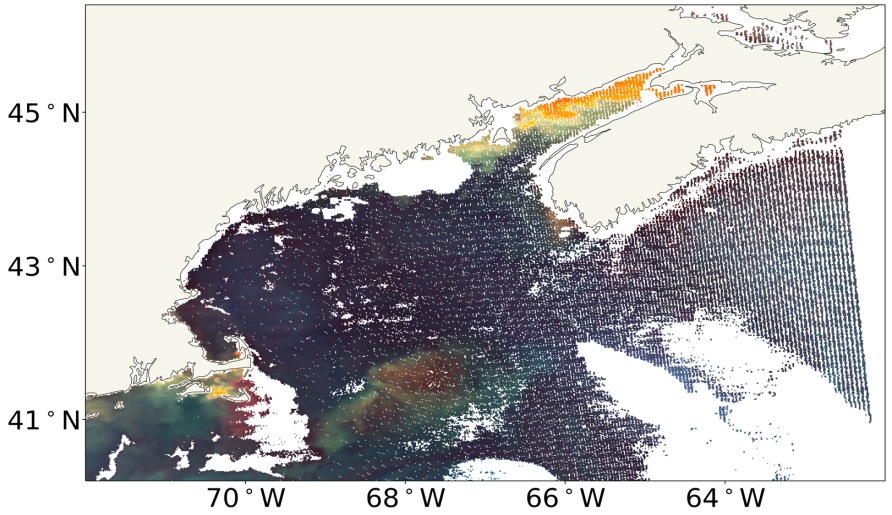
surface Calanus concentration.



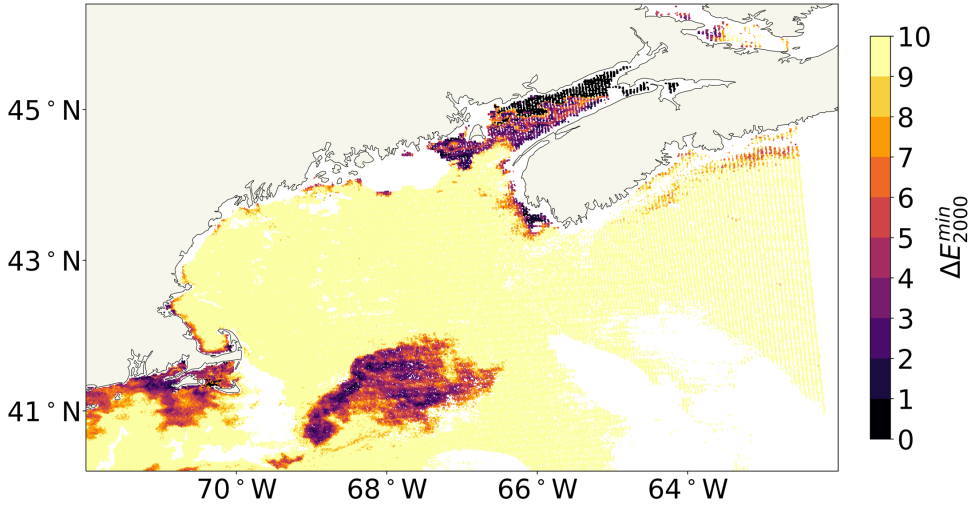
Factors affecting the Calanus estimation: the dinoflagellate *Tripos mulleri* misidentified as calanus

April 13, 2023

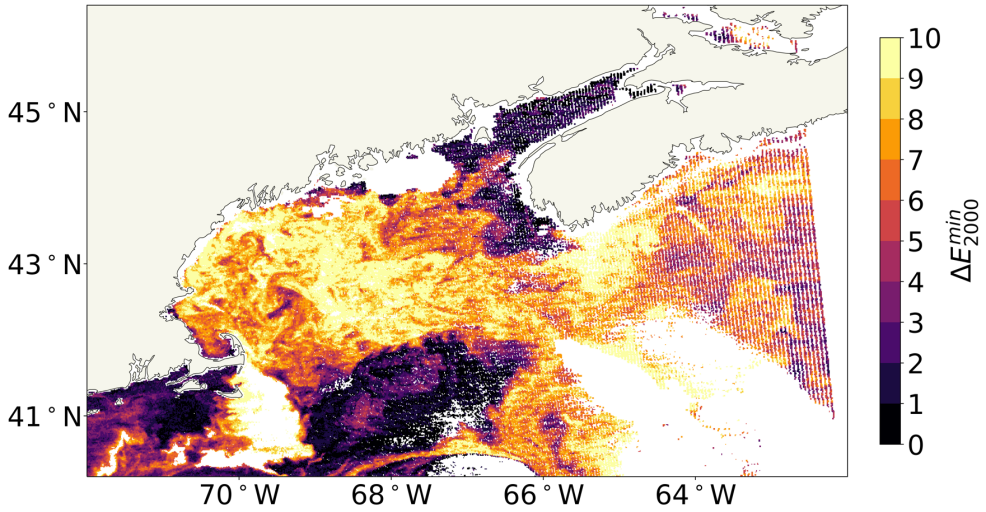
eRGB image



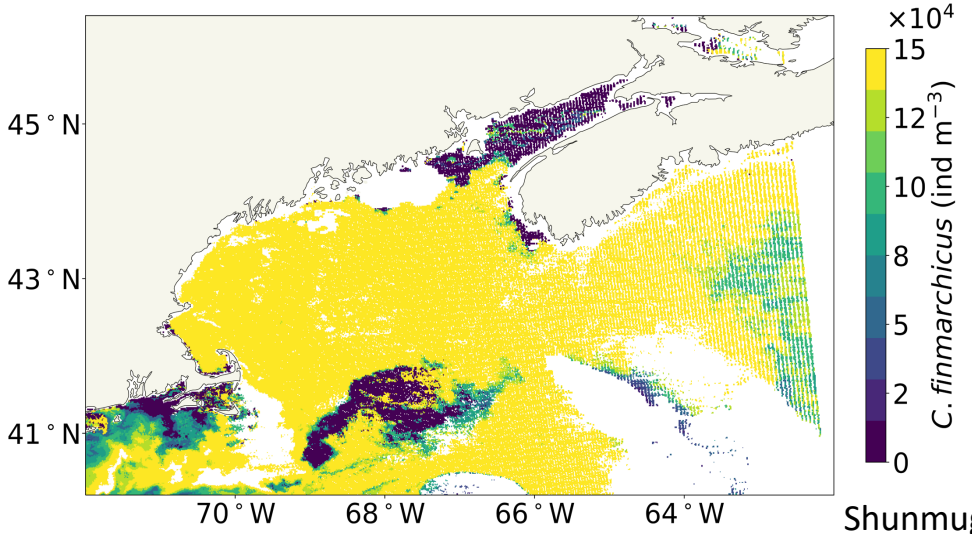
Case 2 ΔE^{min}_{2000} anomaly map



Refined ΔE^{min}_{2000} with Calanus anomaly map



surface Calanus concentration



Shunmugapandi et al. (2025)






0.5 mm

Highlights

- This study highlights the potential of detecting astaxanthin-rich surface Calanus concentration in the Gulf of Maine.

- This approach detects astaxanthin/red plankton rather than estimating the concentration of a specific species. Providing an estimate of astaxanthin concentration would result in a more universally applicable output

- With the current approach, local knowledge is needed to interpret the results (e.g. what species are likely present in the surface waters).

- Underscores the importance of considering optically active zooplankton when evaluating the optical properties of ocean waters.

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Ocean color anomaly detection to estimate surface *Calanus finmarchicus* concentration in the Gulf of Maine

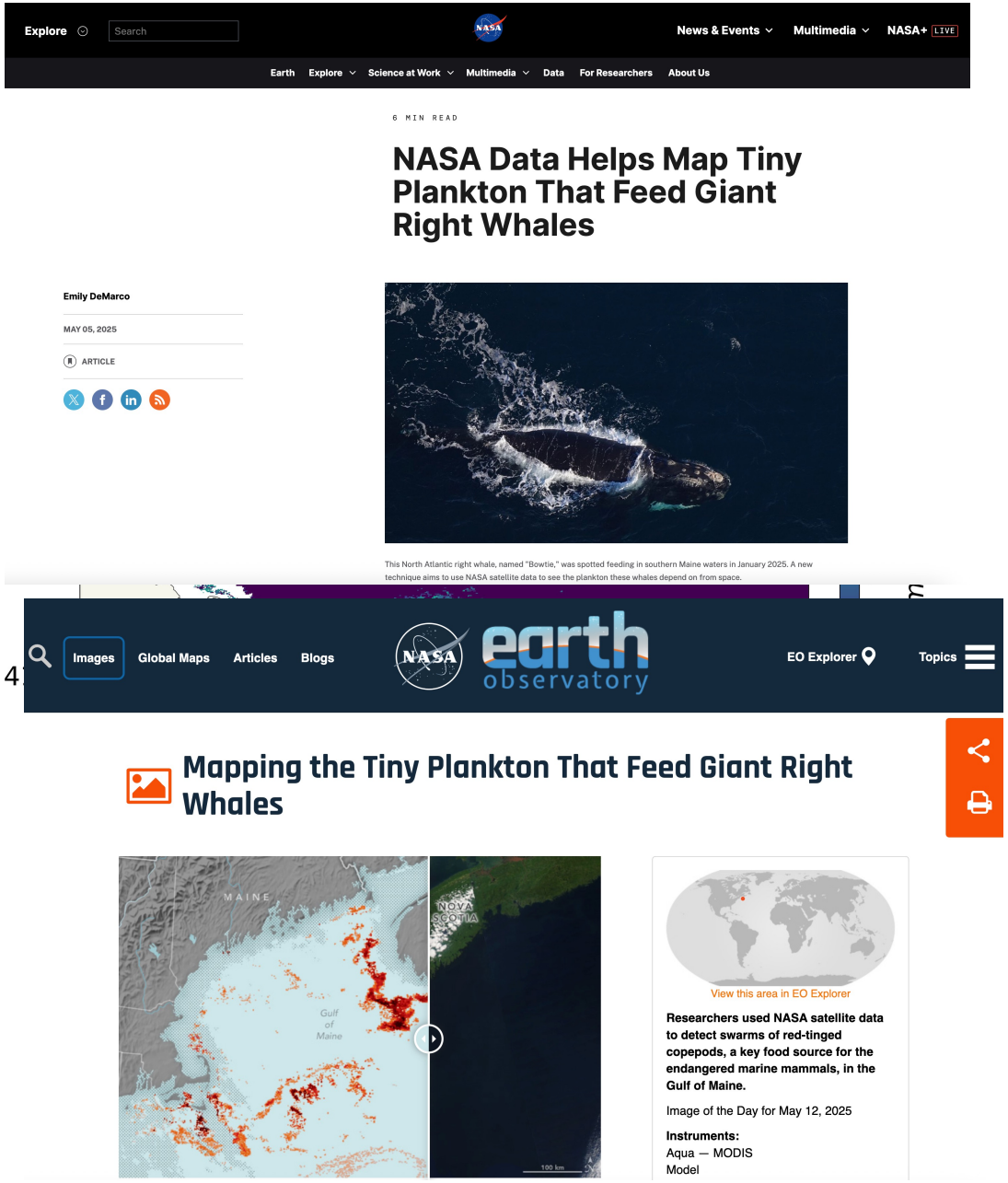
Rebekah Shunmugapandi[1], Cait L. McCarry[1], David McKee[2,3] and Catherine Mitchell[1]*

[1]Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States, [2]University of Strathclyde, Glasgow, United Kingdom, [3]University of the Arctic in Tromsø, Tromsø, Norway

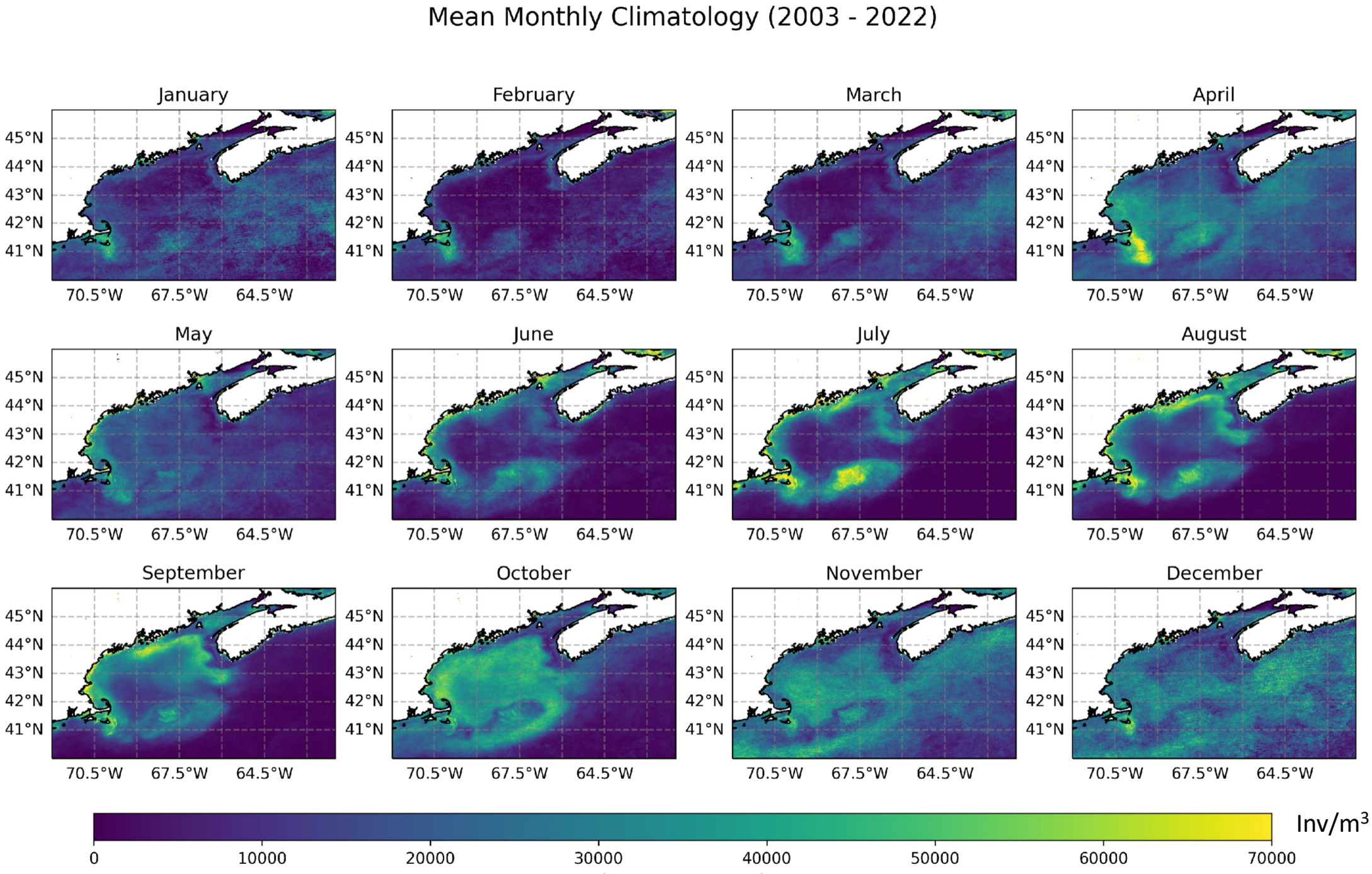
The planktonic copepod, *Calanus finmarchicus*, plays a pivotal role in the Gulf of Maine (GoM) pelagic food web as a primary food source for many species, including the critically endangered North Atlantic right whale (NARW). Thus, observing *C. finmarchicus* on a Gulf-wide scale via satellite could be beneficial for understanding changes in the migration patterns of the NARW. This study investigated the application of ocean color remote sensing to detect the surface population levels of *C. finmarchicus* in the GoM. Using remote sensing reflectance data from the MODIS Aqua sensor, we processed enhanced RGB (eRGB) imagery to detect and quantify the presence of *C. finmarchicus*, which is identifiable by its red astaxanthin pigment. This study employed a refined approach from the method originally developed off the coast of Norway, which integrates eRGB imagery and radiative transfer modeling to generate optical anomaly maps that are used for quantifying surface *C. finmarchicus* concentrations in the GoM. We detected surface swarms of *C. finmarchicus* in the ocean color imagery and estimated their concentrations. However, due to the method's reliance on astaxanthin/red pigment-based detection, other astaxanthin-rich red/brown plankton were misidentified as *C. finmarchicus*. While the approach presented is effective for identifying astaxanthin anomalies in ocean color and holds potential for quantifying the surface populations of *C. finmarchicus*, it requires local knowledge to accurately quantify the *C. finmarchicus* abundances.

KEYWORDS

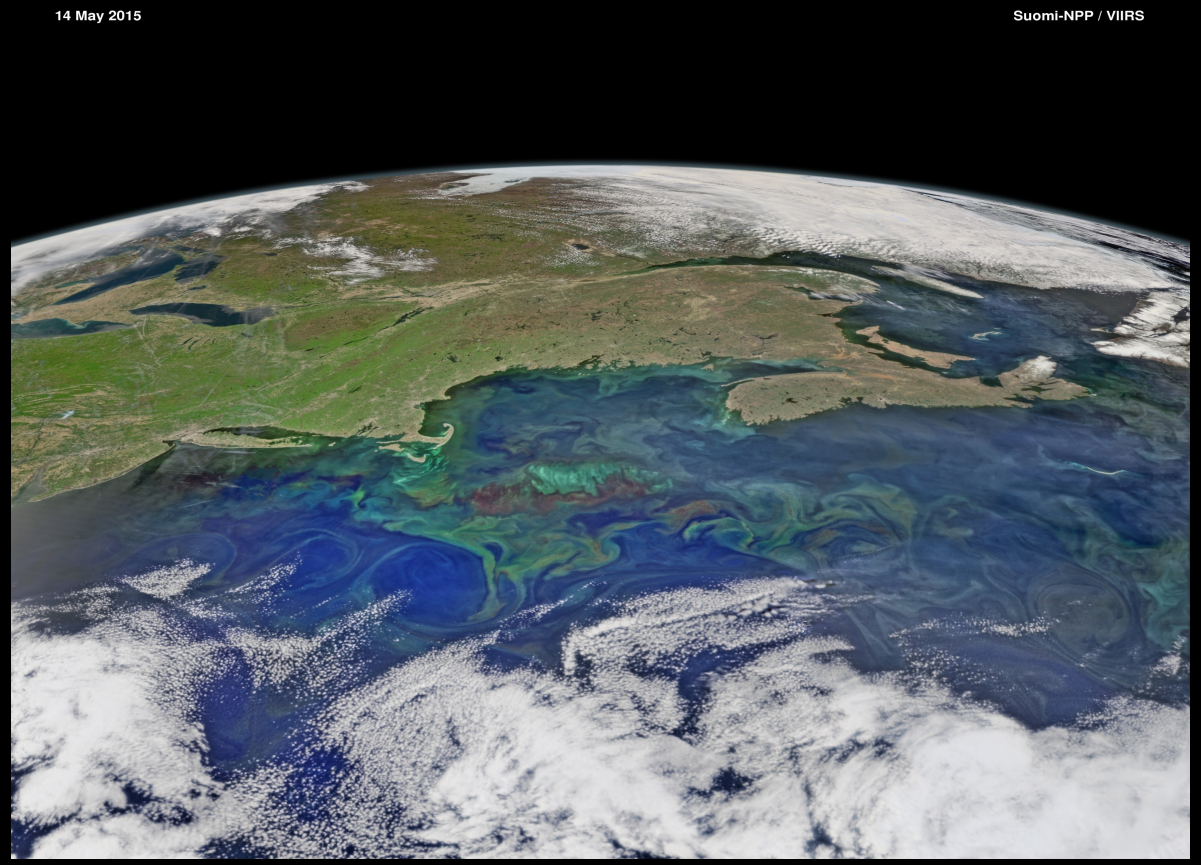
Calanus finmarchicus, zooplankton, ocean color, satellite remote sensing, Gulf of Maine



Shunmugapandi et al. (2025)


Mean Monthly Climatology (2003 - 2022)
January
February
March
April
May
June
July
August
September
October
November
December
45°N
44°N
43°N
42°N
41°N
70.5°W
67.5°W
64.5°W
0
10000
20000
30000
40000
50000
60000
70000
Inv/m3

Marine Optics Lab - BLOS





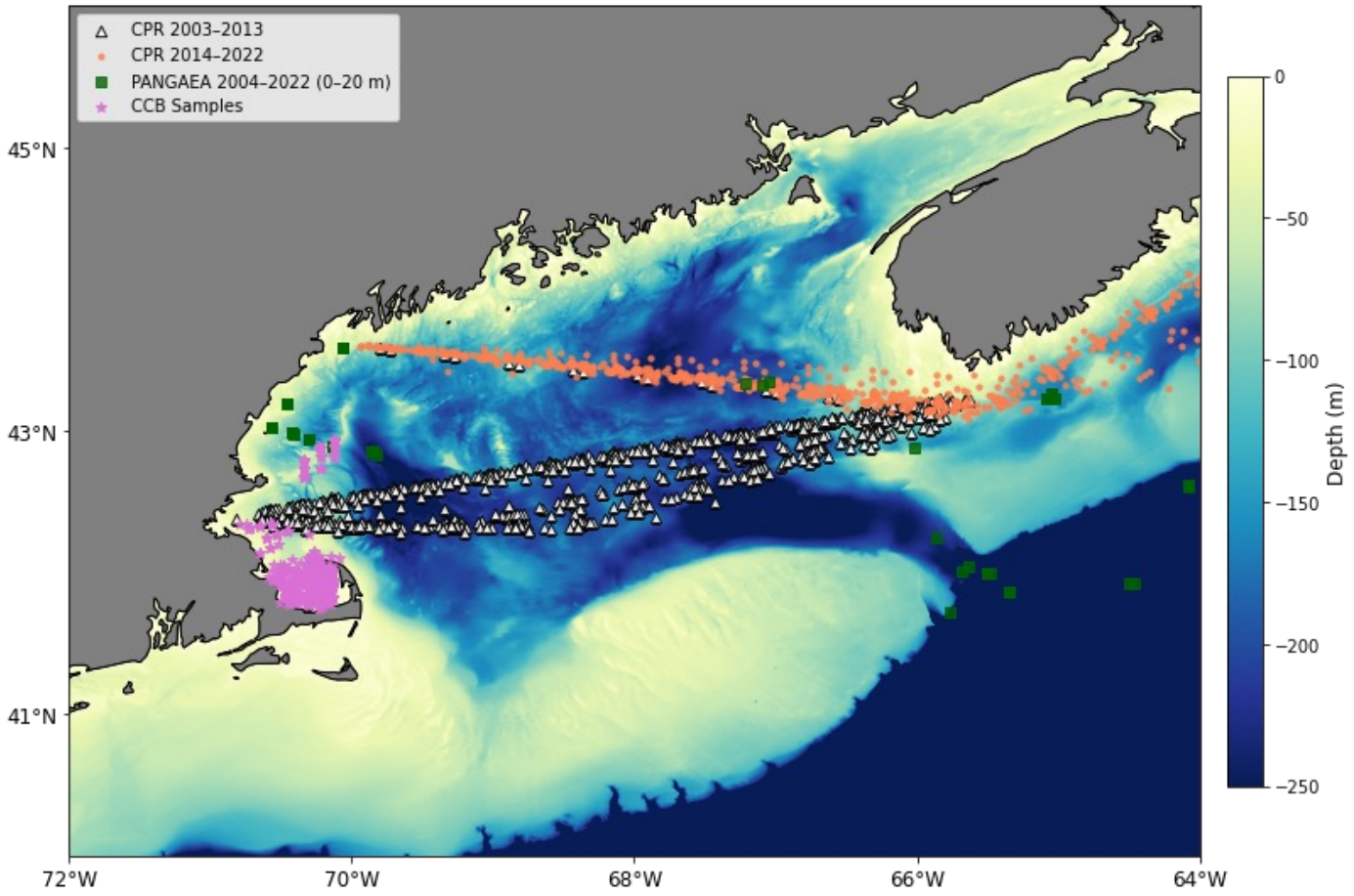







Validation

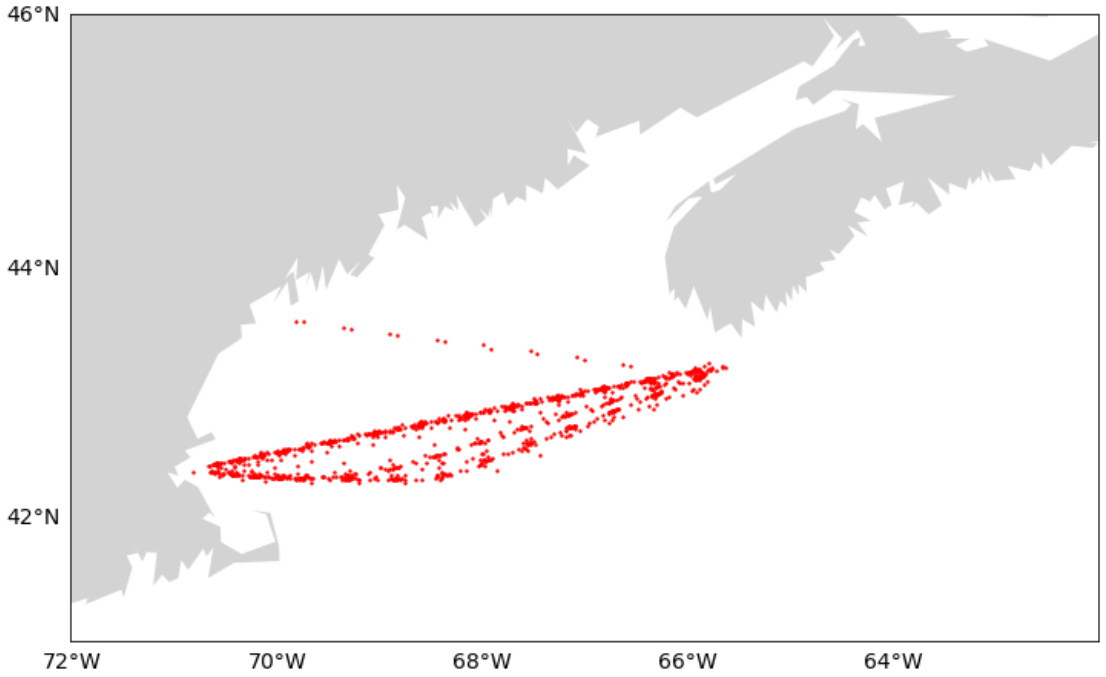
Validation



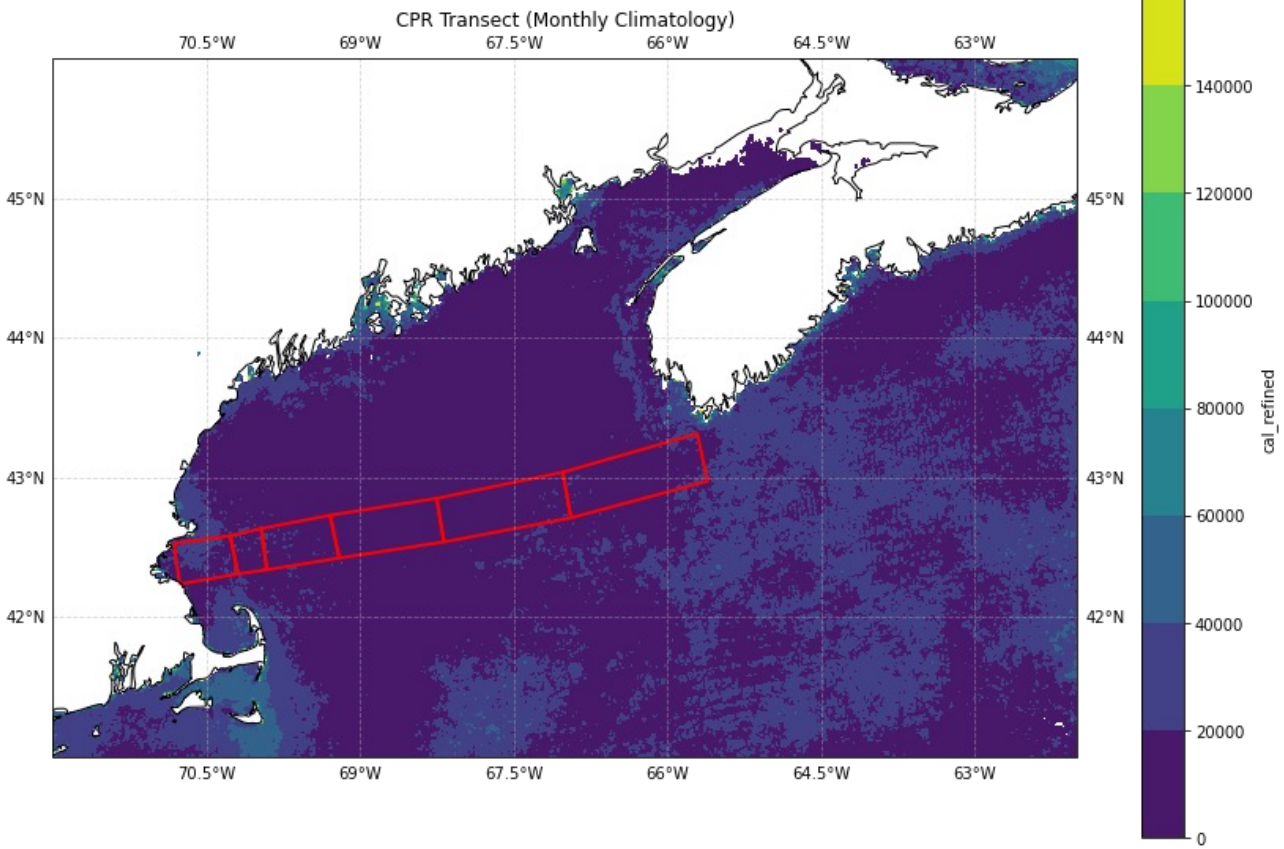
Data	Time frame	Type	Units
CPR	2003 -2013	C5-6, Centropages iv-vi	Idv/ 100 m^3
CPR	2014 - 2022	C1-4, Calanus adults eye count, Centropages	Idv/ 3 m^3
PANGAEA	2004-2022	C-i, C-ii, C-iii,C-iv	Idv/ m^3
CCB	2003-2022	Calanus, Centropages & Pesudocalanus	Idv/ m^3

Validation using in-situ continuous Plankton Recorder(CPR) data

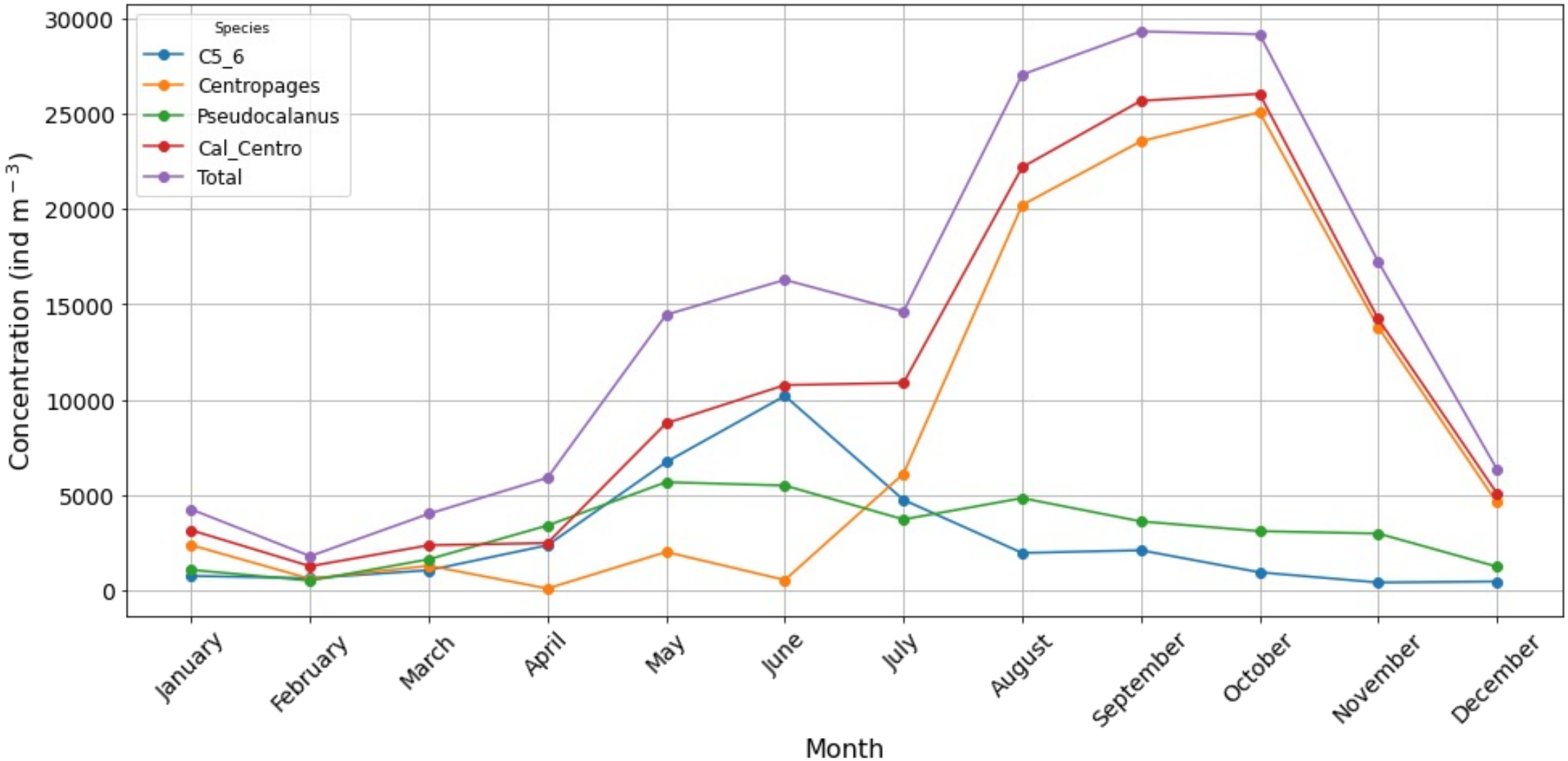
CPR C5-6 2003 - 2013



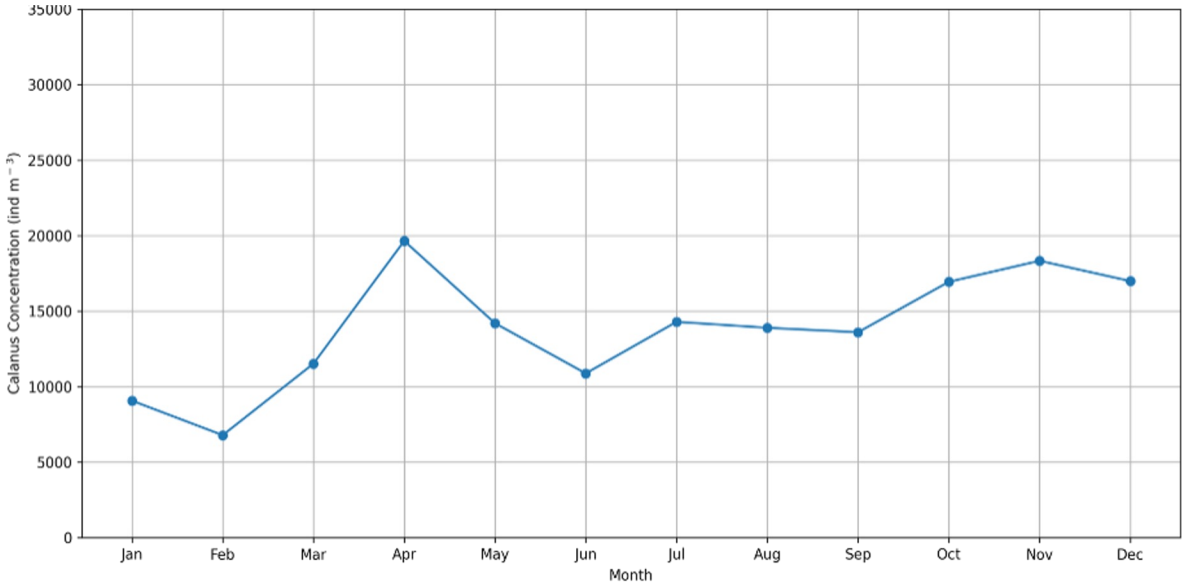
Satellite Calanus



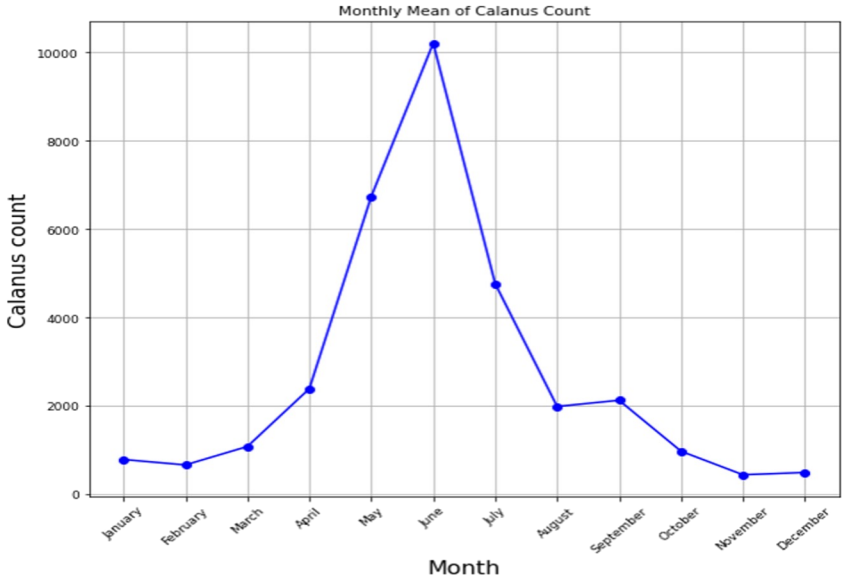
CPR 2003 -2013 insitu data



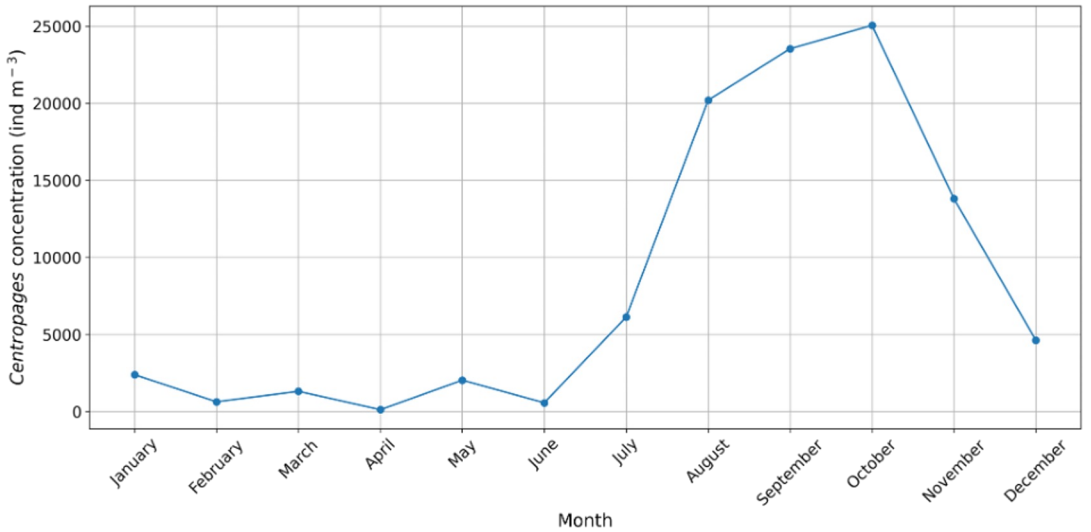
Satellite (2003 -2013)



In situ C5-6 CPR (2003 – 2013)

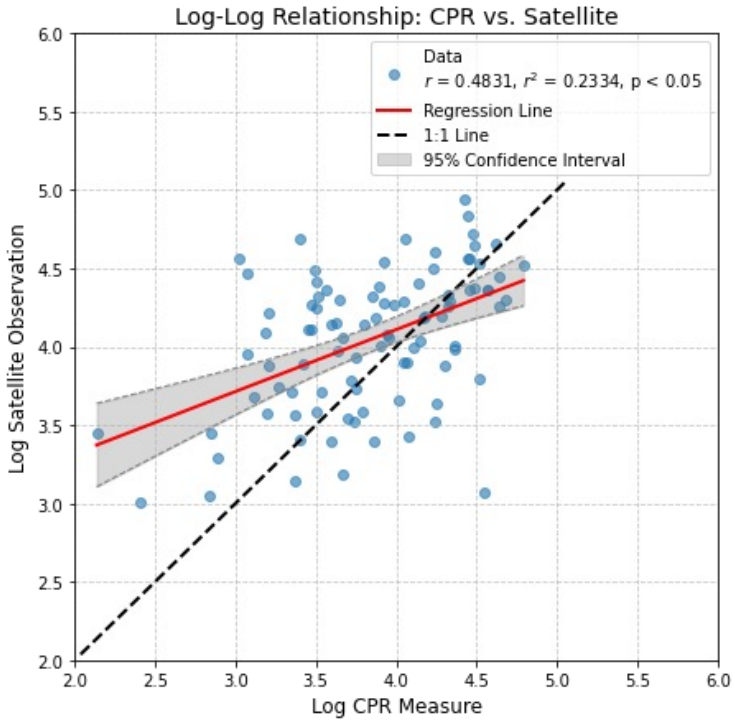


In situ Centropages CPR (2003 – 2013)

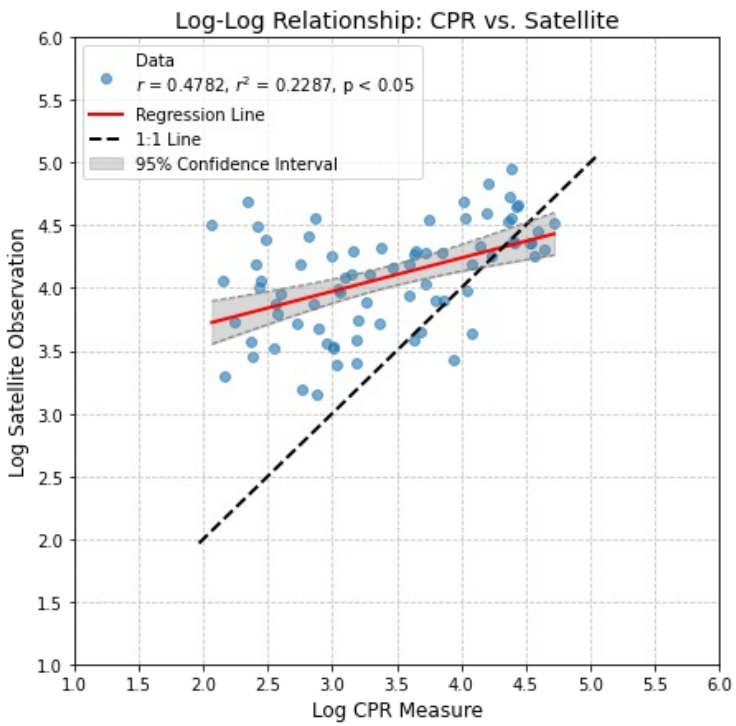


Time-series based

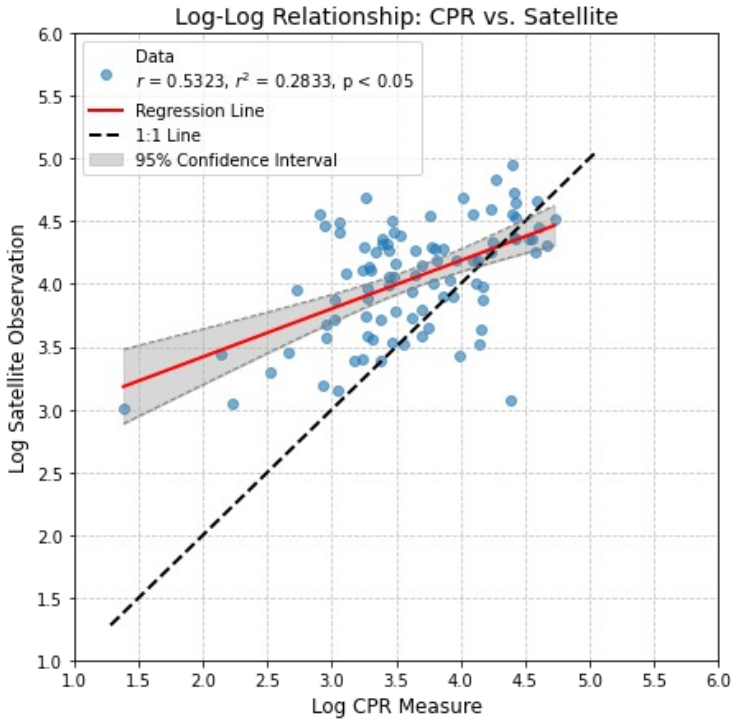
C 5-6



Centropages

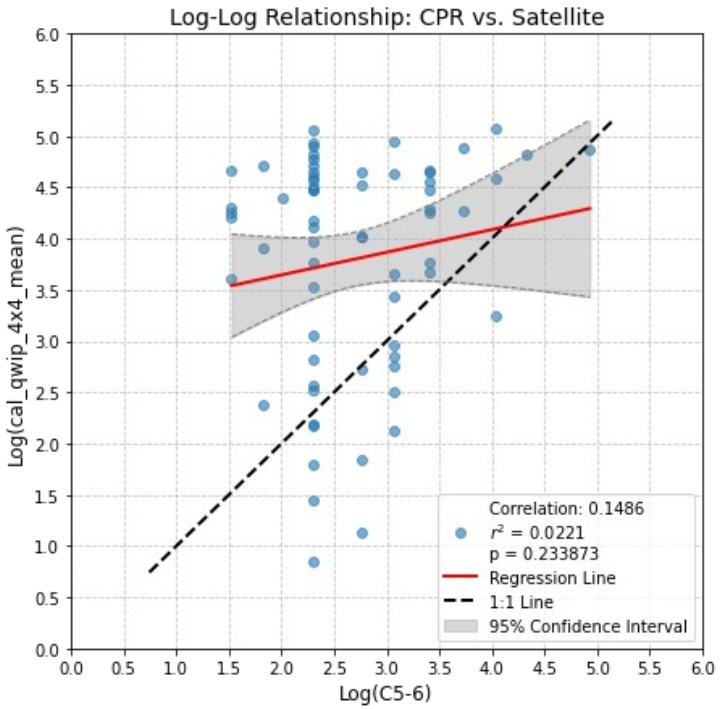


C 5-6 & Centropages

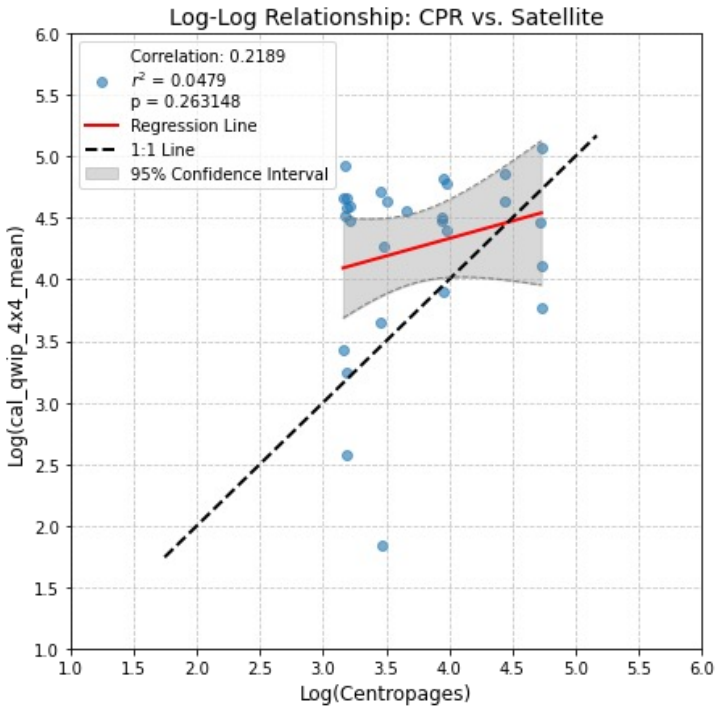


Pixel based

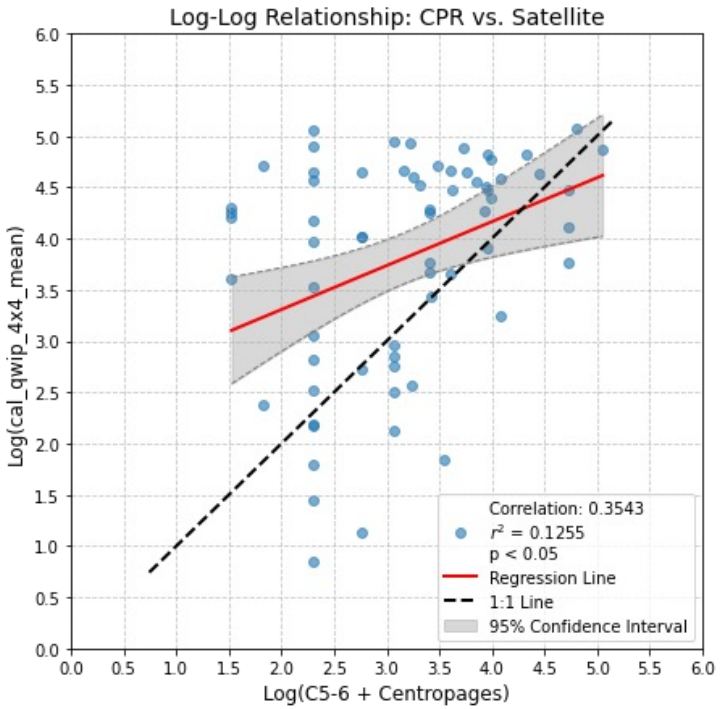
C 5-6



Centropages



C 5-6 & Centropages

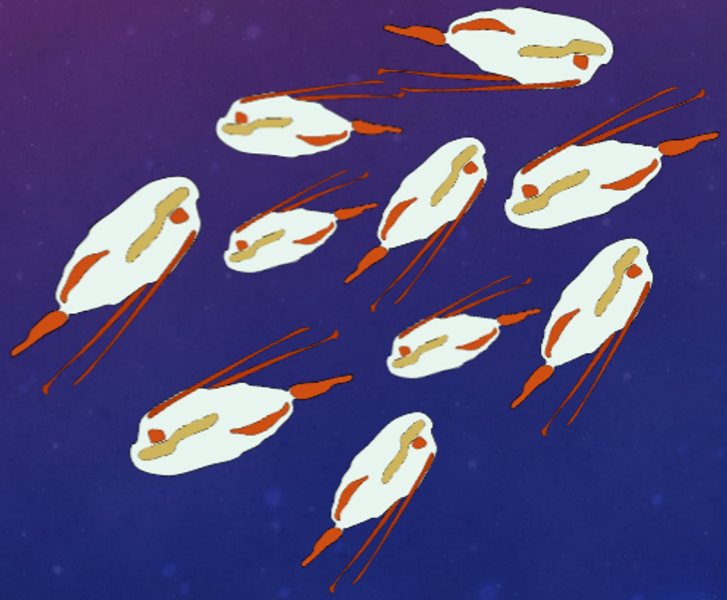


Highlights

- In-situ counts provide the only direct measure of zooplankton abundance, essential for validating satellite-based models or algorithms.
- Vertical migration, net mesh size, and sampling depth can introduce variability and mismatch with satellite surface signals.
- In-situ sampling is logistically constrained and cannot match the synoptic coverage of satellites.
- Measuring in-situ astaxanthin concentration directly can be links to the satellite-observed reflectance more accurately than counts alone.

Potential Applications





Tandy Center for Ocean Forecasting



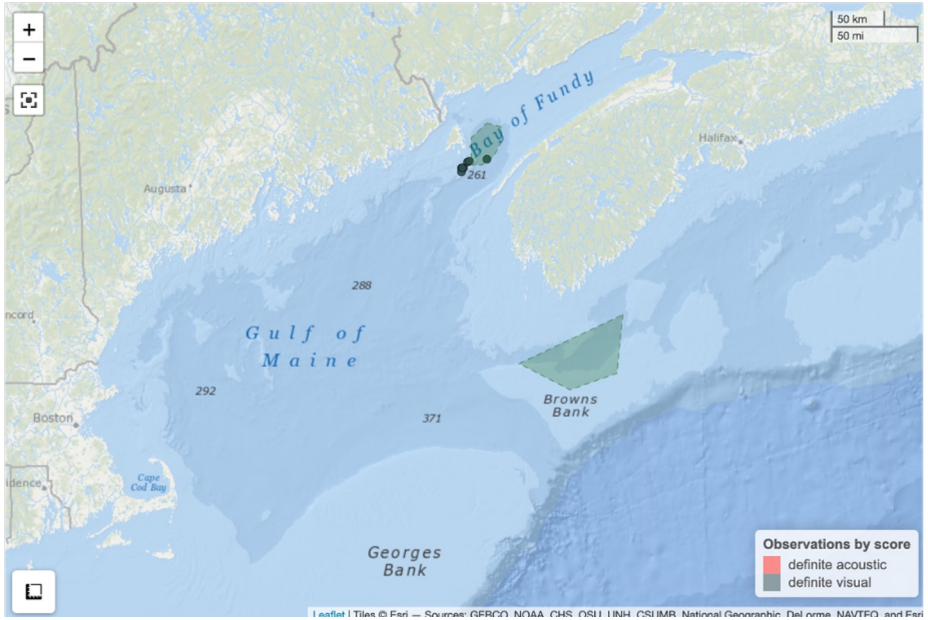


North Atlantic Right Whale



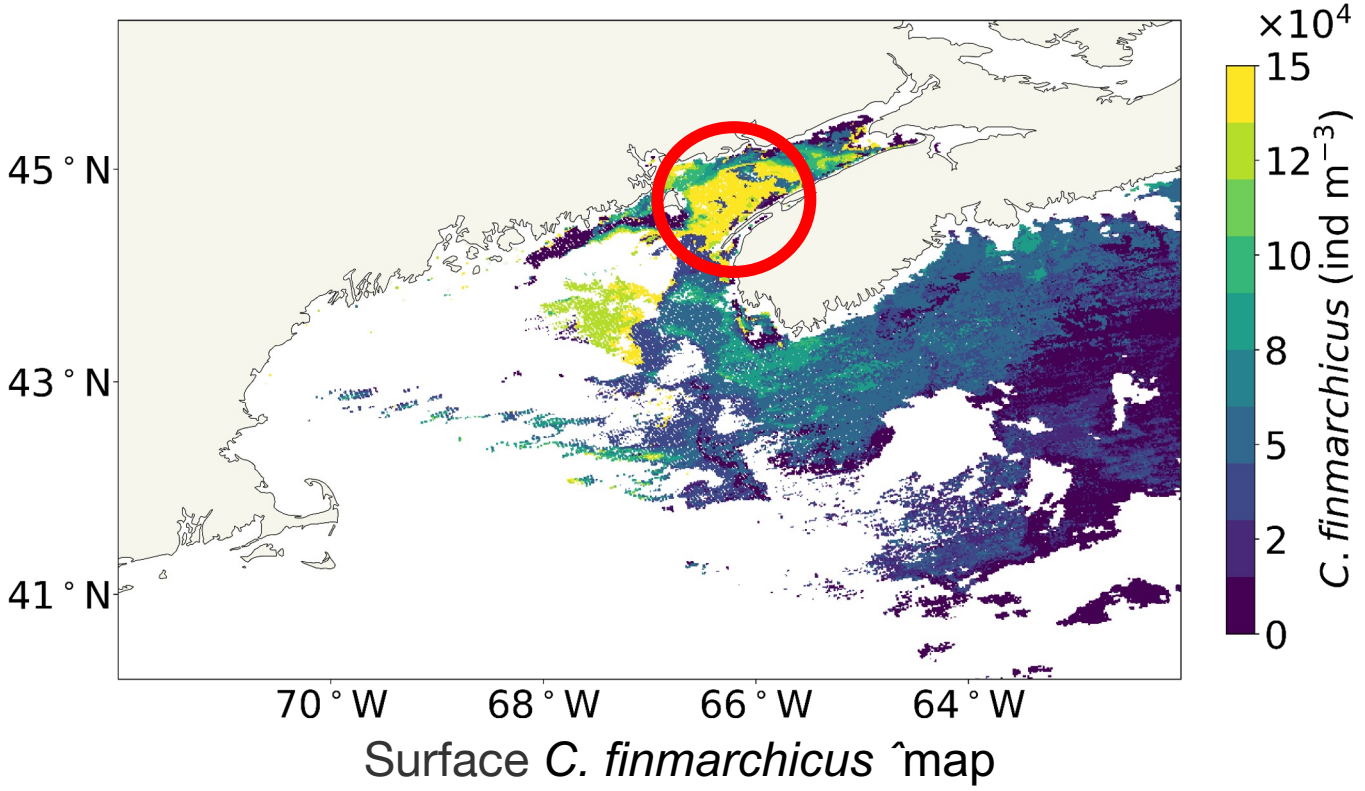
Credit: New England Aquarium, taken under NMFS permit # 25739

Near real time NARW tracking



WhaleMap: NARW observations
(These data are preliminary data, subject to change, and not used for further research)

Species: Right whale
Number of definite sighting events: 7
Number of whales sighted (includes duplicates): 16
Number of definite detections: 9
Earliest observation: 2024-09-29
Most recent observation: 2024-09-30
Most recent position: 44.5267, -66.4433

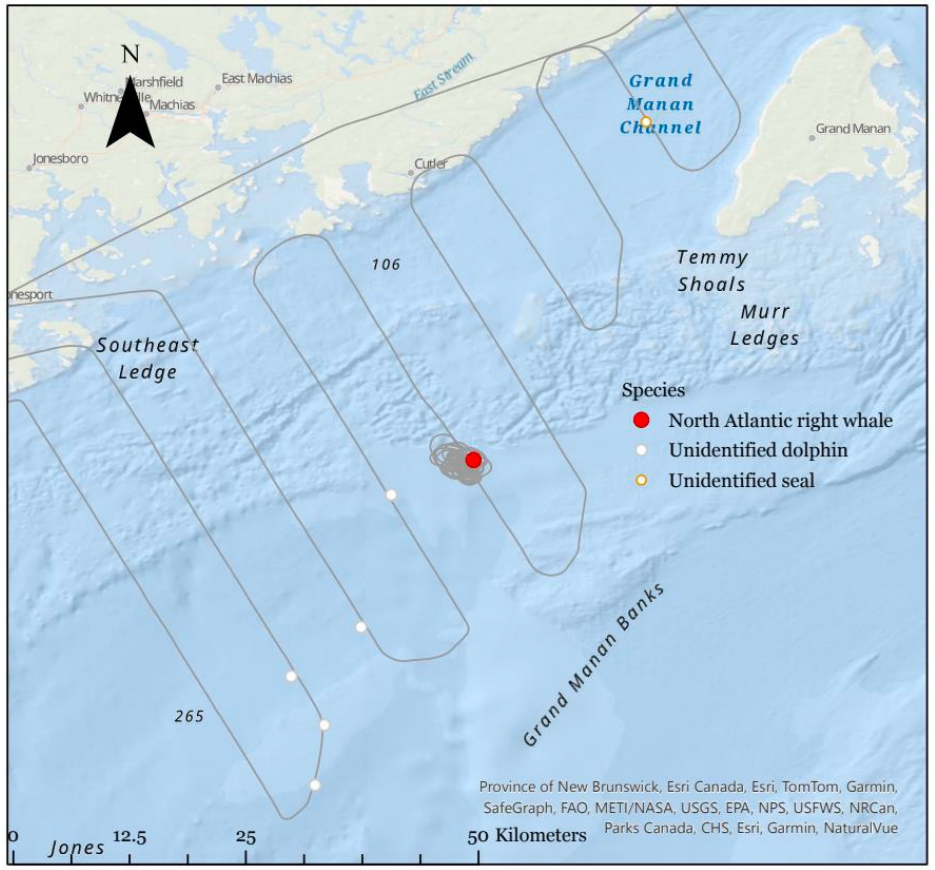


Surface *C. finmarchicus* ˆmap

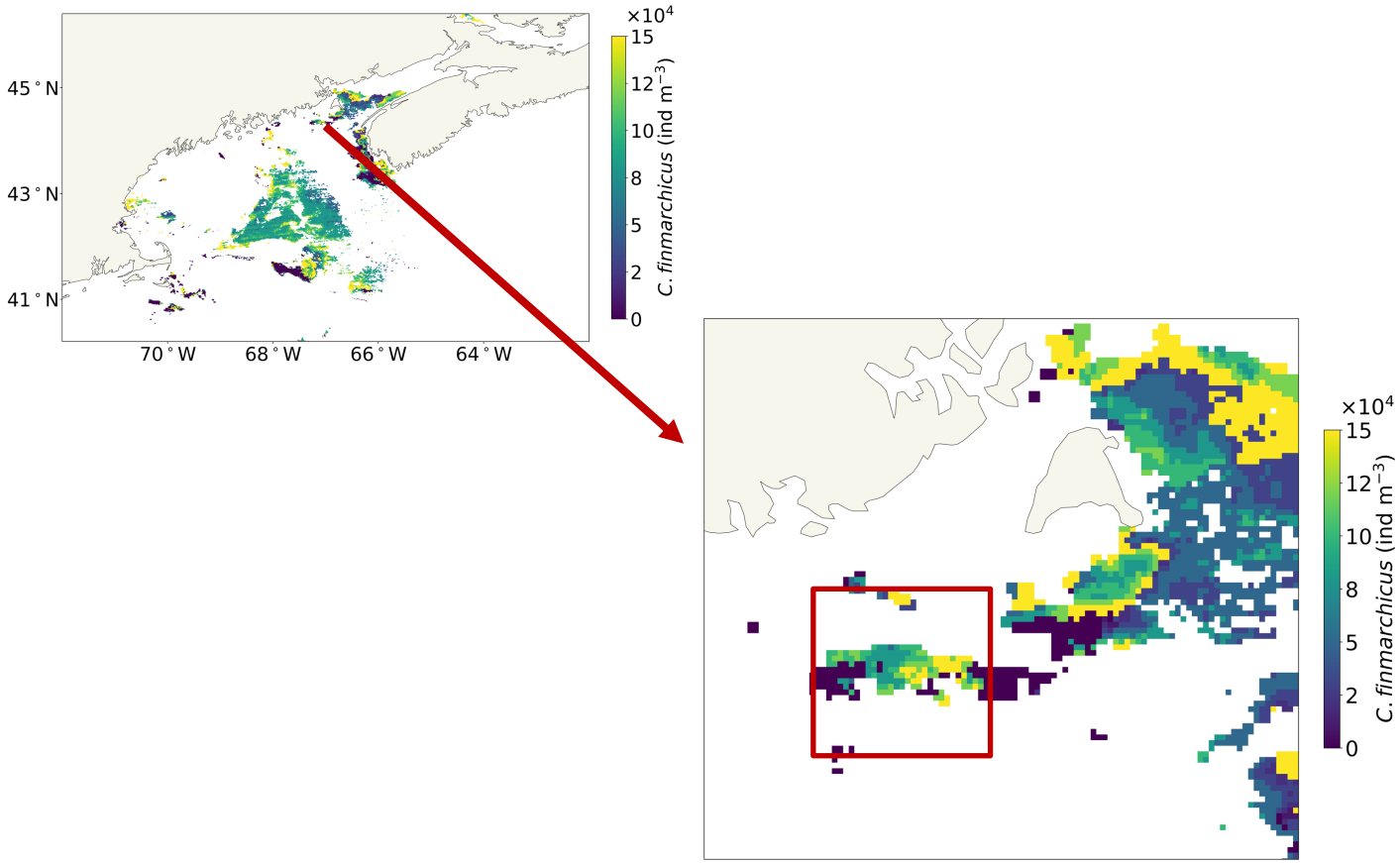
Recent satellite observations of *C. finmarchicus* on September 29th and 30th 2024 reveal a strong alignment between the highest concentrations of *C. finmarchicus* in the Bay of Fundy and the locations of whale sightings recorded on WhaleMap.

Near real time NARW tracking

Aerial Survey Track

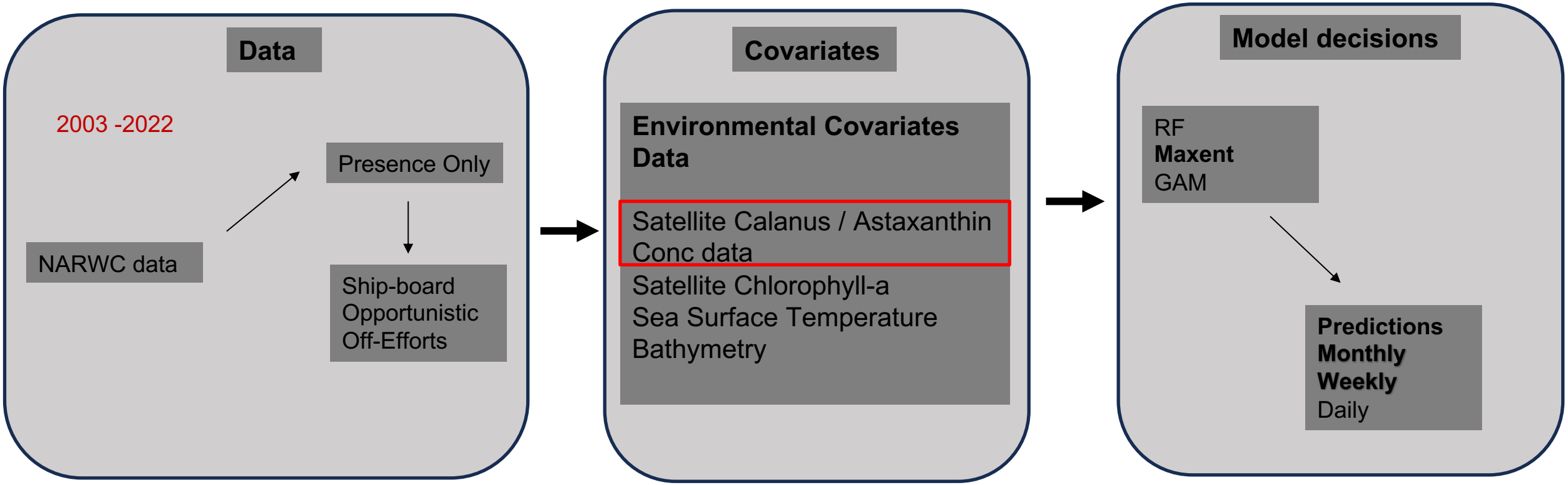


Surface *C. finmarchicus* ˆmap

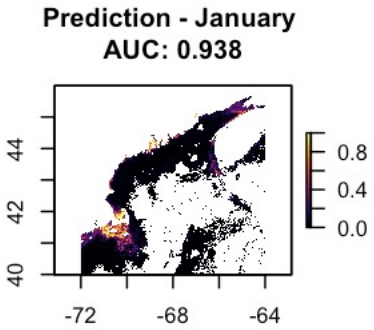


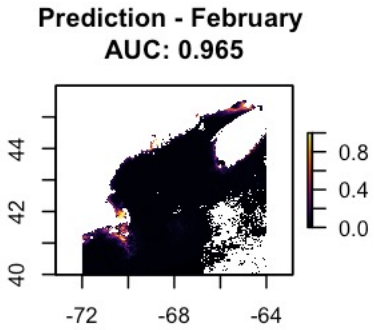
On November 04, 2024, the Maine Department of Marine Resources Division of Marine Mammal Research conducted an aerial survey over Downeast Maine coastal waters. The weather was overcast, and Beaufort sea state ranged from 2-3. A group of 6 North Atlantic right whales was sighted

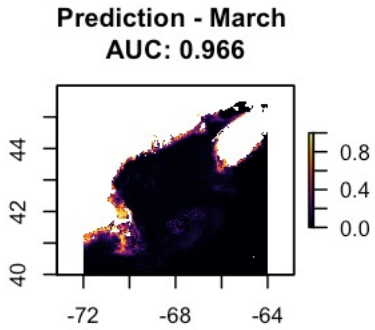
Surface Presence-only Right Whale modelling

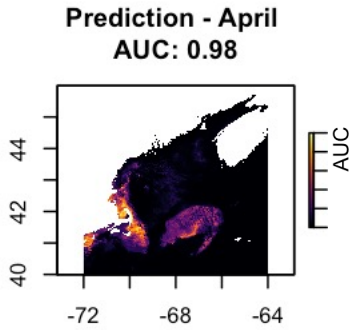


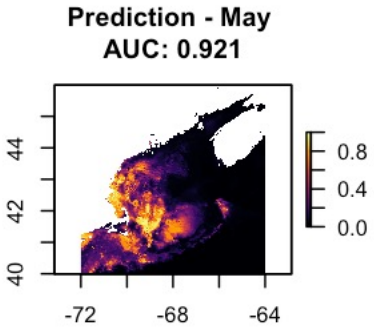
Prediction RW modelling results from sightings opport data

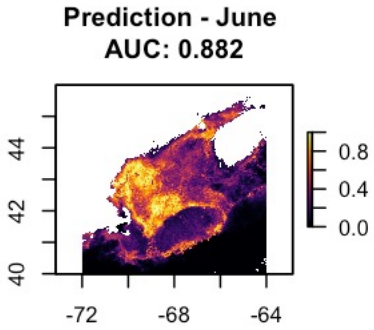


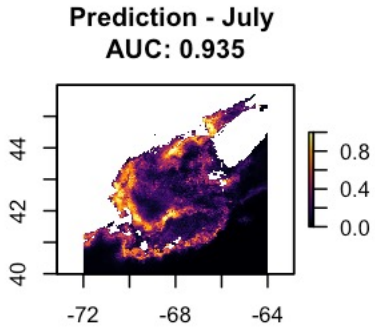


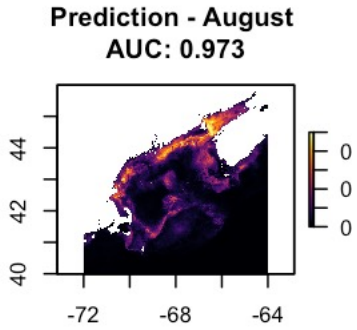


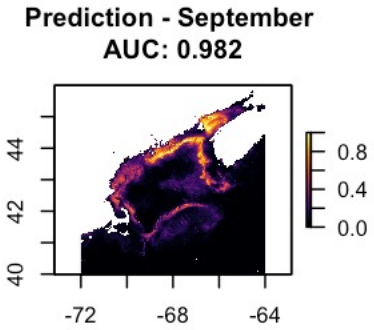


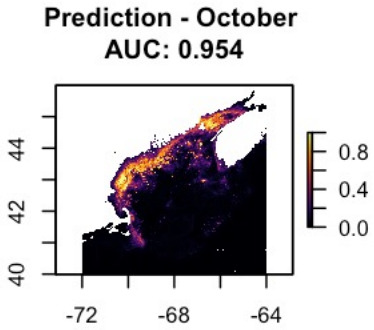


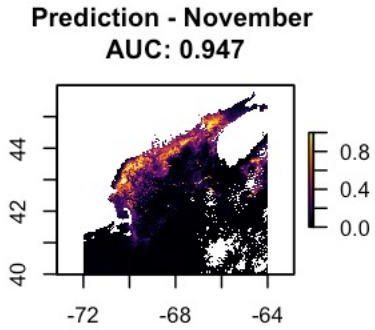


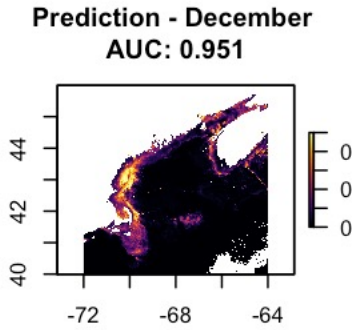


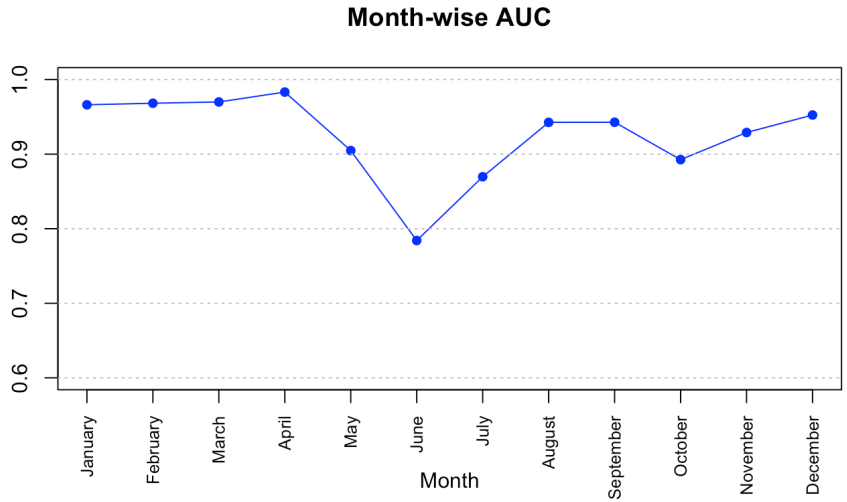


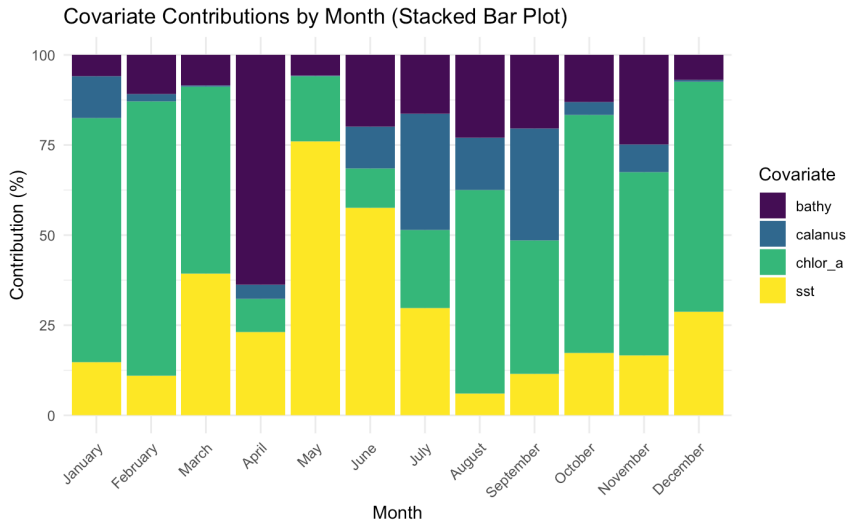




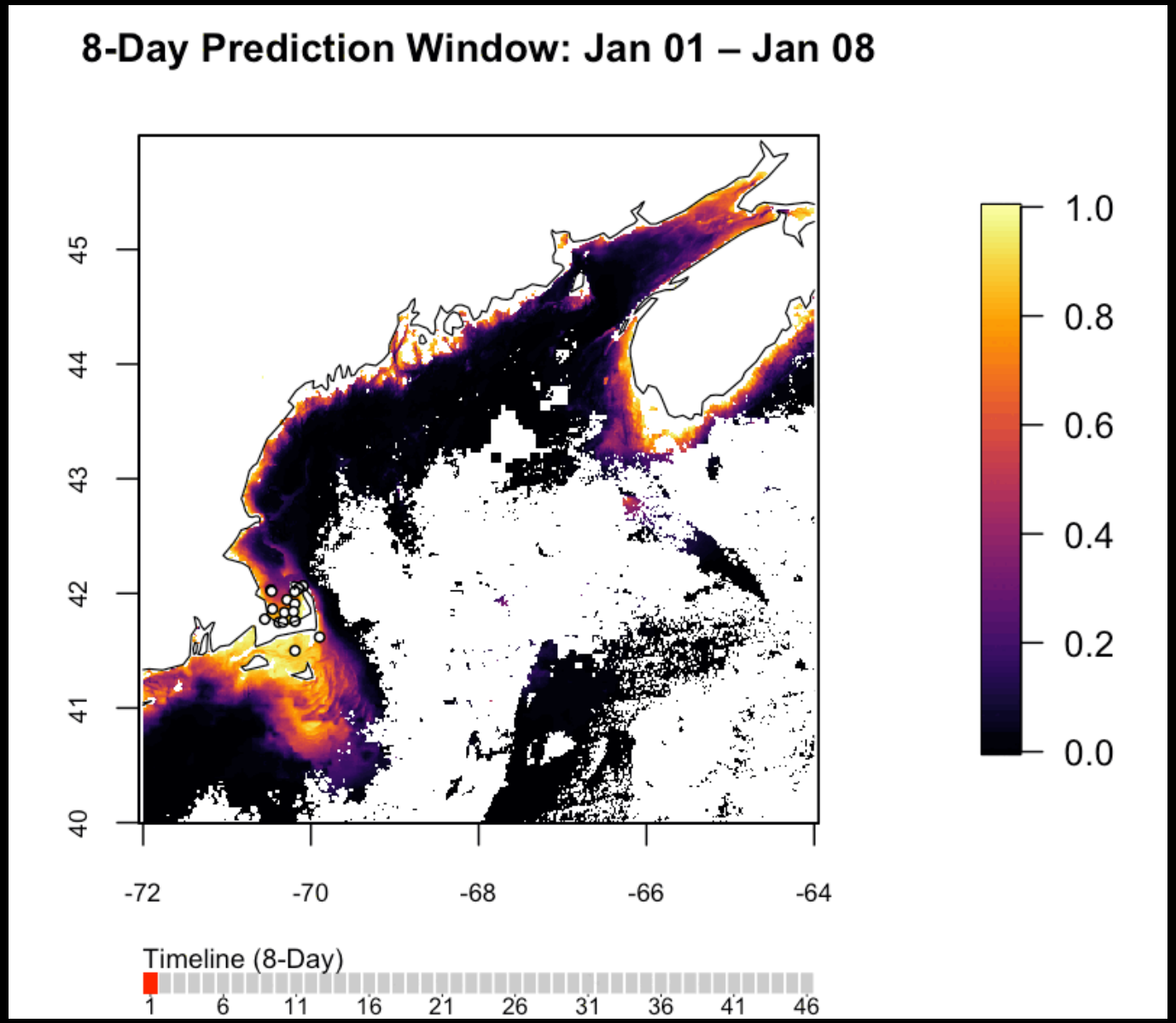








8-Day prediction from monthly using opportunistic sightings data



Highlights

- Broad spatial coverage: Satellites can monitor large ocean areas where in-situ sampling is not feasible.
- High temporal resolution: Frequent revisits allow near real-time updates on potential whale foraging areas.
- Early warning for conservation: Identifies *Calanus*-rich zones that may attract right whales, supporting proactive management and protection.
- Enables creation of dynamic risk maps based on real-time *Calanus* abundance and ocean conditions.

Acknowledgement

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Maine Department of
Marine Resources (DMR)