

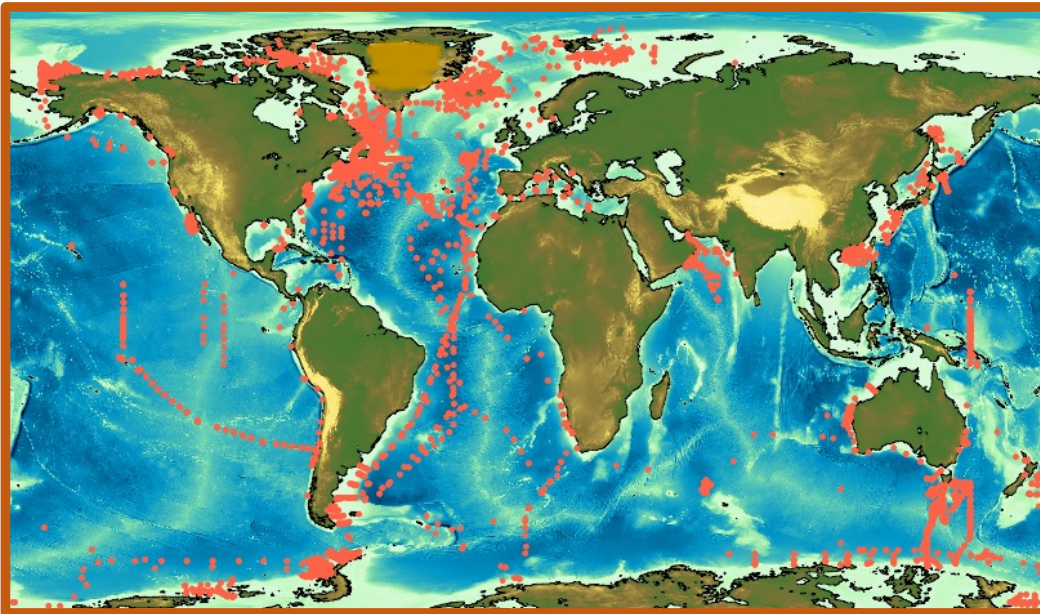
Photosynthetic characteristics of marine phytoplankton across ocean biomes

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A GLOBAL PHOTOSYNTHESIS-IRRADIANCE (P-E) DATASET



One of the aims of the ESA BICEP project is to expand existing global datasets of the photosynthesis-irradiance (PE) parameters. This data mining effort has dramatically improved both the spatial and temporal coverage of these parameters that are critical to convert maps of surface chlorophyll to estimates of water-column primary production. We have used the > 10,000 experimental measurements and metadata assembled as part of the BICEP project to explore how changes in environmental forcing and the taxonomic structure of phytoplankton communities are related to the PE parameters. Here we focus on 'regions of interests' that cover three ocean biomes defined by Longhurst [1]. These ocean biomes (Polar, Coastal, and Trades) represent the primary unit of biogeographic division of the global ocean and provide a useful way of examining difference in variability caused by large-scale changes in environmental forcing. Our dataset reveals biome-specific differences in phytoplankton photophysiology.

Temperature was the most recorded environmental variable in the global dataset. The temperature-dependent relationship of the assimilation number (P_m^B) for each biome is shown along with the equations that have been used to assign the chlorophyll-normalized maximum photosynthetic rate using remotely-sensed sea-surface temperature. Note that all experimental data was fitted to the equation of Platt et al. [2] to obtain the initial slope (α^B) and the photosynthetic rate at saturating irradiance (P_m^B) and cells were incubated at ambient temperatures.

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POLAR BIOME – THE ATLANTIC ARCTIC

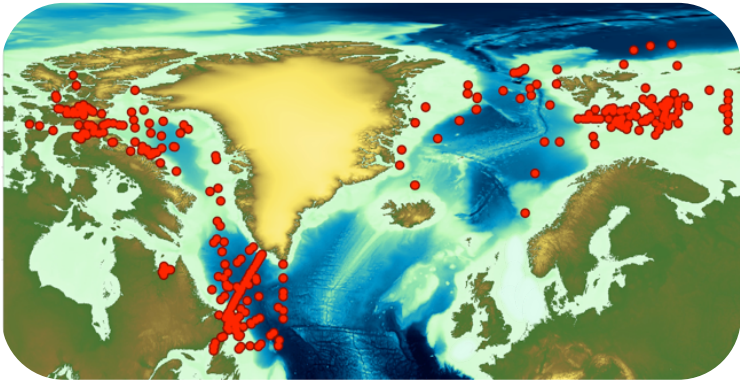
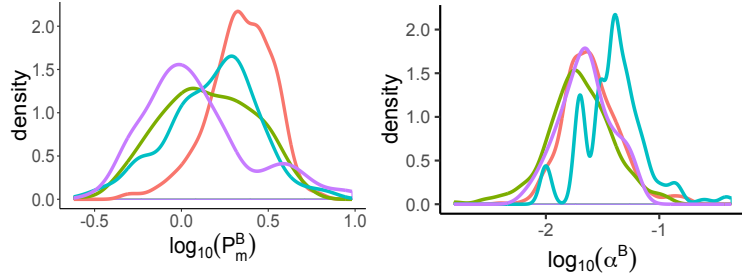


Fig 1. This dataset covers polar and subpolar waters over a latitudinal range 50 to 83°N. Chlorophyll-a concentrations ranged from 0.01 to 25.3 mg m⁻³.

REGIONAL VARIABILITY



- LABRADOR
- CAN ARCH
- BARENTS
- GREEN/NORW

Fig 2. Density plots of the *PE* parameters for the four Atlantic sector regions (Labrador Sea, Canadian Archipelago, Barents Sea and Greenland/Norwegian Seas).

Fig. 2 shows regional differences in the variability in both *PE* parameters. P_m^B values were lower in the Greenland Sea and higher in the Labrador Sea whereas α^B was higher in the Barents Sea. **Fig. 3** shows the relationships between the *PE* parameters and environmental variables (temperature (*T*), nutrient concentrations, sampling depth (*z*) and chlorophyll-a concentration (*Chl*)). The results are consistent with previous studies: P_m^B is positively correlated with temperature [3,4], whereas α^B tends to be positively associated with nitrate concentrations [5]. Despite their differential response to physicochemical forcing, the two parameters are positively correlated to each other [6, 7, 8].

Fig. 4 shows the positive correlation between the photosynthetic parameters. Note there is a fanning out of points from the origin, denoting a significant range of E_k values.

Temperature has been widely used as an indicator of the maximum photosynthetic rate (P_m^B). In **Fig. 5** we show two functional forms describing the temperature dependence of P_m^B . The Eppley curve [3, 9] (blue) tends to form an envelope at the 25th percentile, whereas the seventh-order polynomial [3] (red) falls closer to the median at low temperatures and the 75th percentile at higher temperatures. Note that a considerable amount of variability in this parameter remains unexplained, consistent with the findings of several field studies [6, 10, 11].

ENVIRONMENTAL VARIABILITY

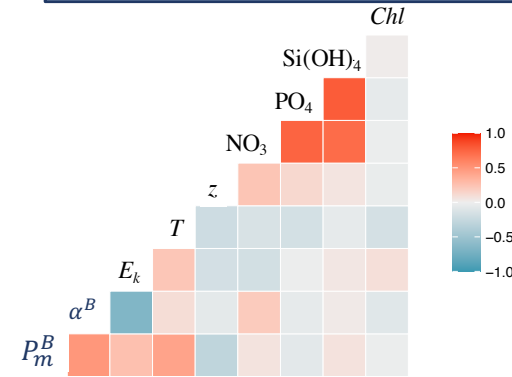


Fig 3. Spearman correlation matrix of photophysiological parameters and environmental variables. *T* is temperature and *z* is depth.

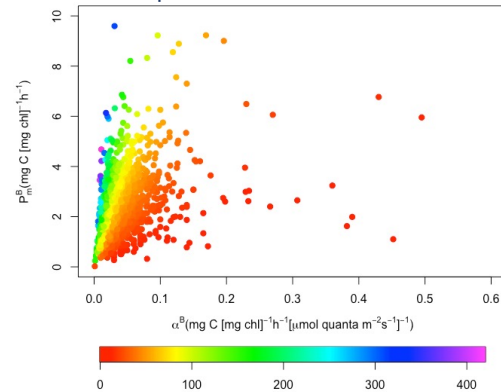


Fig 4. The correlation between the photosynthetic parameters P_m^B and α^B with their corresponding E_k values denoted by symbol colour.

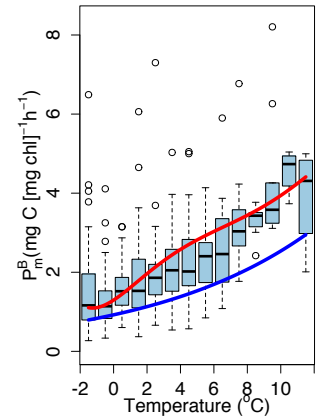
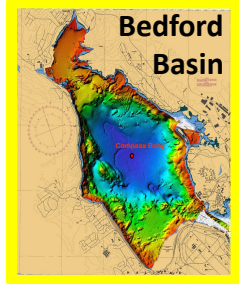
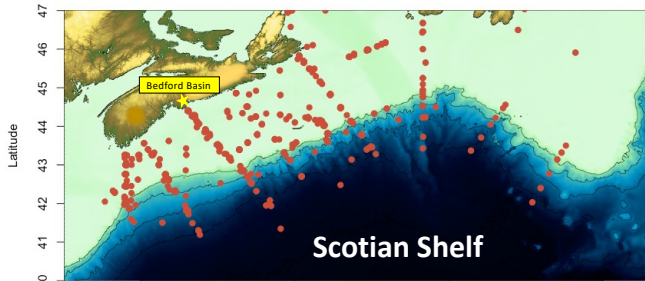


Fig 5. Boxplots of P_m^B for every 0.5°C Increment. Bottom and top of the box represent the 25th and 75th percentile. Central band represents the median.

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COASTAL BIOME – SCOTIAN SHELF AND BEDFORD BASIN



Weekly to tri-weekly sampling was conducted in Bedford Basin at its deepest point (70 m – Compass Buoy Station shown on left (44°42.3'N, 63°39.2'W). PE experiments were conducted at 5 m covering all seasons. The Scotian Shelf cruises were typically conducted every spring and fall as part of the Canadian SOLAS programme. PE experiments were typically done at the sea surface and the chlorophyll maximum.

For the shelf waters off Nova Scotia, there is a positive relationship between temperature and P_m^B . (Fig 6a, Fig 7a). When we combine results of photosynthesis-irradiance experiments conducted over a series of seasonal studies over many years, a similar temperature dependence emerges for Bedford Basin (Fig 6b, 7b), although the lower end of the temperature range (<7°C) shows more variability. Both parameters are negatively correlated to Fucoxanthin/Chla, a proxy of diatom presence. The degree to which other environmental factors (vertical stability, light, nutrient supply and community structure) are responsible for these patterns remains to be elucidated. Nevertheless, these results clearly demonstrate that seasonal changes in the environment have a pronounced influence on algal photophysiology.

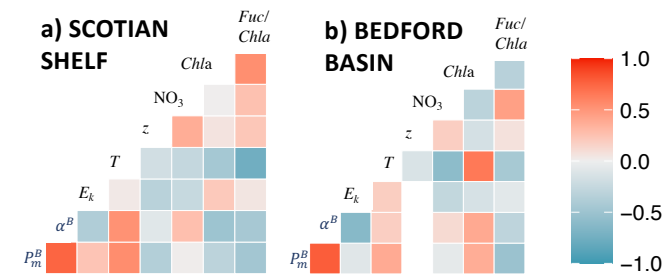


Fig 6. Spearman correlation matrix of photophysiological parameters and environmental variables. T is temperature, z is depth and Fuc/Chla is fucoxanthin normalised to chlorophyll-a.

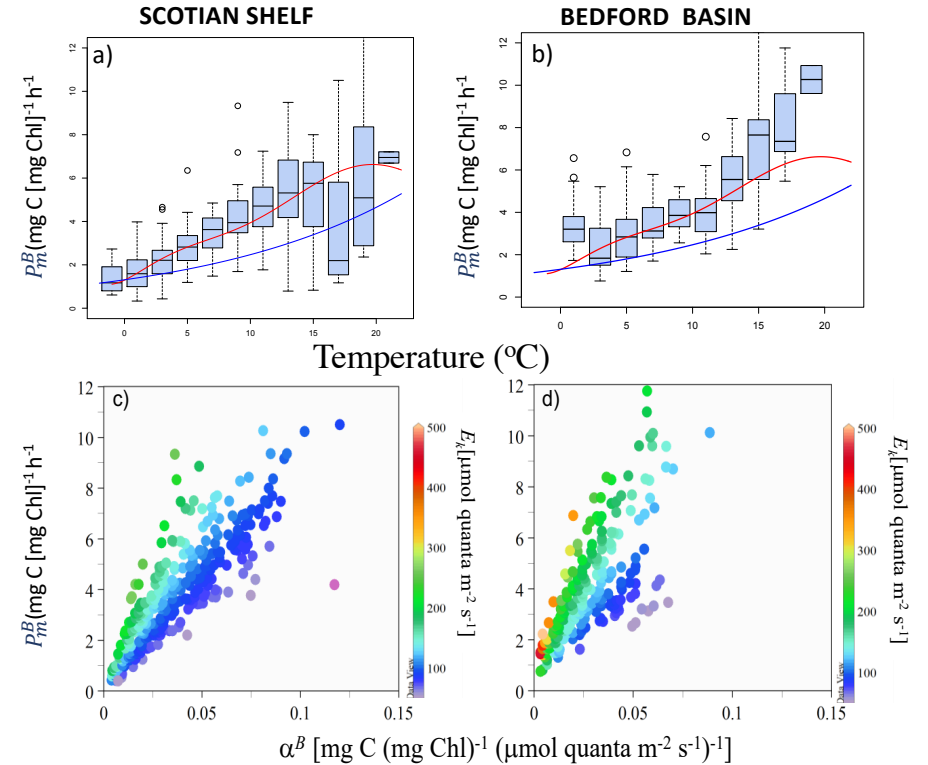
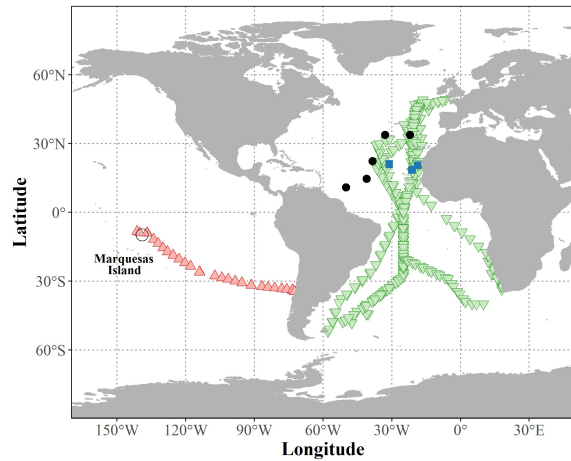


Fig 7. Boxplots of P_m^B as described in Fig. 5. Scatterplots showing the relationship between the photosynthetic parameters.

In Bedford Basin positive correlation between P_m^B and α^B is also observed (Fig. 6b, 7d) and is more constrained than that of the Polar Biome. However, the plot also shows that the wedge of data points fall within a wide range of E_k values (50 to 500 $W m^{-2}$). To examine how this relationship between P - E parameters compares with those obtained in offshore waters, we also plotted the P - E parameters from samples collected within the surface waters (0-20 m) on the Scotian Shelf (Fig 7c). The range of E_k values from the Shelf are more constrained (100-250 $W m^{-2}$) which implies that the surface waters of the Scotian Shelf may offer a more stable light environment than that of Bedford Basin.

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TRADES BIOME – THE OLIGOTROPHIC GYRES



▲ AMT
 ▲ BIOSOPE
 ● DCM
 ■ EUMELI

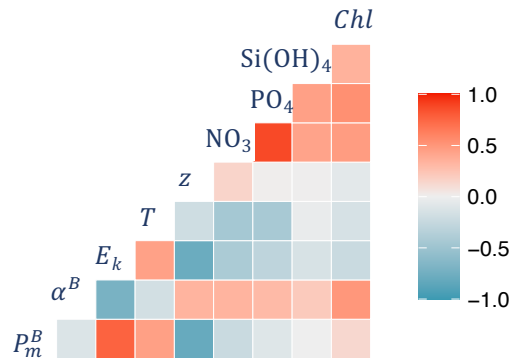


Fig 8. Spearman correlation matrix of photophysiological parameters and environmental variables. T is temperature and z is depth.

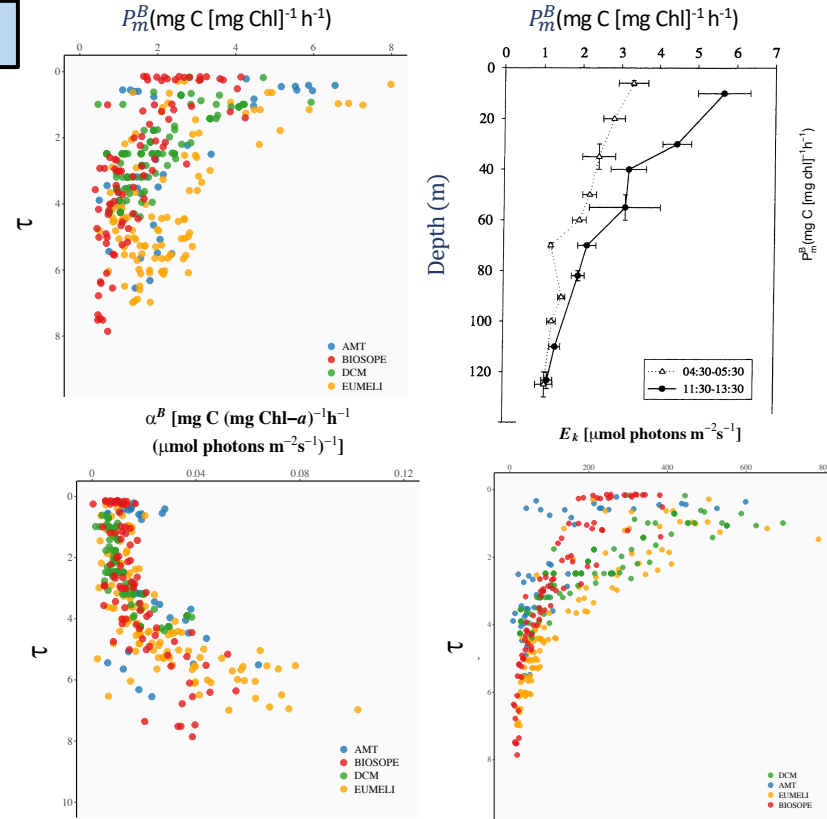


Fig 9. P_m^B , α^B and E_k plotted against the optical depth (τ). The top right panel also shows the diel changes in the assimilation number at various depths in the photic zone.

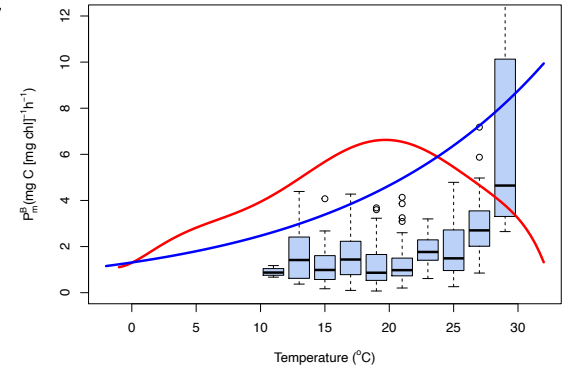


Fig 10. Boxplots of P_m^B as described in Fig. 5.

For the Trades Biome, vertical changes in the photosynthetic parameters are particularly strong (Fig 9) and P_m^B and α^B are weakly correlated with each other (Fig 8, 9). This is caused by a strong photoacclimatory response of the cells to decreasing light levels. For this biome, P_m^B values are much lower than those predicted by the temperature-dependent equations (Fig. 10). Note that there is a strong diel response in the assimilation number and this dampens with depth (Fig 9, top right-hand panel). The diel response in α^B was not as pronounced.

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Significant variability in the photosynthetic parameters was observed within the three ocean biomes. Although a positive relationship between the assimilation number and temperature was detected for the polar and temperate coastal systems, our results show that a significant amount of the variability remains unexplained.

Looking forward, we envisage a mechanistic and ecological approach is required to account for a larger fraction of their overall variability, which necessitates the collection of a suite of taxonomic and environmental data alongside *PE* experiments.

Priorities

1 year – Develop standard protocols for photosynthesis-irradiance experiments to allow datasets to be readily comparable. Assemble a list of ‘desirable’ ancillary measurements.

5 years – Data mine online repositories to match up PE experimental data with physical, chemical and biological variables known to govern photosynthetic rates. Add new data, targeting undersampled regions of the ocean.

10 years – Examine the utility of fluorescence-based approaches (e.g. Rapid Light Curves) to better understand the spatiotemporal variability in the PE response curve.

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