# Introduction

Polar phytoplankton are \*\*vital\*\* to polar ecosystems [@pierellakarlusich2020; @ardyna2020]. As photolithotrophs, phytoplankton rely on photons **flow** for energy input, nominally restricting their **growth** to the photic zone, defined as the region where sufficient light for photosynthesis penetrates, **traditionally** extending down to 1% of surface irradiance [@ravenPutOutLight2000; @kirk2011]

Despite severe light constraints, certain polar phytoplankton exhibit slow but significant growth under the ice during winter, indicating possible photosynthetic adaptations **to maintain net growth under** light limitation [@randelhoff2020; @hancke2018; @leu2015]. To **drive linear electron flow** during photosynthesis, Photosystem II (PSII) needs four sequential photons, with risk of loss through futile charge recombination, if the photon arrivals are too widely spaced.

We hypothesized that maintaining photosynthesis under extremely low light and low temperatures involves \*\*suppressing energetically wasteful charge recombinations\*\* in PSII.

![Figure 1: Recombination Pathways of PSII \*note: this figure will be simplified into a view of electron transport pathways in the thylakoid membrane with recombination pathways highlighted before the final presentation\*](figure\_recombination.png)

# Methods

Recombination causes a slippage in the four**-**step cycle for a PSII, and thus cause desynchronization of the steps, across the population of Photosystem II [@gates2020]. For each PSII the yield of fluorescence varies across the four steps, and if PSII are synchronized, the cells show four-step cycling of chlorophyll fluorescence. Therefore, \*\*variable chlorophyll fluorescence\*\* can be used to evaluate the synchronization of the PSII. By inference, prolonged synchronization implies low recombination, and vice versa [@schubackSingleTurnoverVariableChlorophyll2021; @zaharievaEnergeticsKineticsSState2019].

![Figure 2: Single-turnover variable chlorophyll fluorescence approach for monitoring PSII cycling of phytoplankton photosynthesis](StChlF.png).

* **3 comments:** 
  + **Very easy to read and understand.**
  + **Drive S-State cycle: Perhaps add the insertion of 2H2O at S4 -> S0. I wonder about the relevance of adding sequential proton production. After all, they play an important role in the process.**
  + **Monitor ChlF: just to make sure I've got this right, is the fluorescence value the same as Fm? If so, it might be useful to specify this**.

We used Fast Fourier Transforms to analyze the persistence of PSII chlorophyll fluorescence cycling across polar and temperate diatoms or green algae, under a range of light and temperatures, todetermine if polar taxa have evolved to increase photosynthetic energy conversion efficiency, by minimizing inefficient recombination reaction.

# Results

![Figure 3: Duration of significant cycling PSII chlorophyll fluorescence cycling in polar and temperate diatoms or green algae, under a range of light and temperature conditions](heatmap.png)

We observe \*\*3\*\* key patterns between and within taxa

\* Within taxa, shorter spacing of photon delivery, and colder temperatures, result in stronger cycling of PSII chlorophyll fluorescence, and by inference, less wasteful recombination.

**The Damping Index sort of represents the amplitude value of your wave? If that's what it is, it's not so easy to understand. Make sure you explain it clearly to your audience.**

\* Polar taxa exhibit significant PSII cycling across a broader range of conditions, at wider spacing of photons, equivalent to lower light, than do their temperate counterparts

**To make sure you understand, are you comparing the response of each in relation to its ecological niche (or optimal growth temperature value)? For example, for the taxa Thalassio, Chlamydomonas rein. and Chlorella vulg. you don't know what happens for temperature values >10°C and >12°C respectively ? All this is comparatively analysed at their specific optimum growth rates, right? If that's the correct case, perhaps you could describe it briefly. I can well understand that polar lenses have a higher D.I. at more widely spaced photon flashes, but I'm not so sure about the temperature range. Have you tried to see what happens to temperates at temperatures >10°C?**

# Conclusions

Our findings indicate that diverse polar phytoplankton have evolved capacities to sustain efficient photosynthesis under extreme low light and low temperatures, by suppressing wasteful recombinations at PSII.

This research challenges the conventional understanding of the limits on photosynthesis under light limitation, helping unravel polar ecosystem dynamics and predict ecosystem responses to climate change