学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Photophysiological responses of marine phytoplankton and ice algae to temperature, iron and light availability in subpolar and polar regions
（亜極域・極域に生息する海洋植物プランクトンおよび海氷微細藻類の温度・鉄・光利用度への光合成生理応答）

Global warming increases sea temperatures and intensifies stratification of the water column, which directly and indirectly affects marine ecosystems and biogeochemistry (e.g., less nutrient supply due to the stratification). It has been suggested that the effects of climate change may emerge earlier in subpolar and polar regions, which are highly productive from spring to summer and ecologically important (e.g., phytoplankton blooms and ice algal production). In these regions, an increase in temperature may benefit some algal primary producers, but contracts extent of sea ice, which is an inhabitant of ice-associated biota. Light is also a crucial factor for all photosynthetic organisms, and its availability can change dramatically by sea ice melt. Iron (Fe) as a micro-nutrient plays a key role in algal metabolic processes including photosynthesis. This study thus aimed to clarify the effects of temperature, light and iron (Fe) availability on the photophysiology of phytoplankton and ice algae in the changing subpolar and polar oceans.

Effects of temperature on a spring diatom bloom in the coastal Oyashio (COY) were investigated as a representative subpolar coastal spring bloom. The spring diatom blooms in COY waters are highly productive in spite of the low sea surface temperature (SST) (−1−2 ºC in early spring). This study thus focused on the photophysiology and community composition of phytoplankton in COY waters during the pre-bloom and bloom periods from March to April 2015. Next-generation sequencing targeting the 18S rRNA gene revealed that the diatom *Thalassiosira* generally dominated the phytoplankton community in COY waters on the shelf (shelf COY). Additionally, the relative contribution of *Thalassiosira* to the total diatom assemblages showed a positive correlation with maximum photosynthetic rates (P^{B}_{max}) throughout this study, suggesting that the genus largely contributed to the bloom. We also conducted short-term on-deck incubation experiments to clarify the role of temperature in determining the photosynthetic functioning of phytoplankton. As a result, in the shelf COY, rising temperature led an increase in P^{B}_{max} and transcription levels of the diatom-specific *rbcL* gene coding the large subunit of RuBisCO. It suggested that the rising temperature upregulated the diatom-specific *rbcL* gene and then triggered the higher P^{B}_{max} as well as the spring diatom bloom in the shelf COY waters.

Sea-ice algae contribute 10–25% of the annual primary production of polar seas, and seed large-scale ice-edge blooms. Large fluctuations in temperature, salinity, light and Fe availability, associated with freezing and melting of sea ice, can significantly change the photophysiology of ice algae. Therefore, effects of multiple co-stressors (i.e., freezing temperature and high brine salinity in a freezing event; and sudden high light exposure during ice melting as well as Fe starvation) on the photophysiology of ice algae were investigated in a series of ice tank experiments with the polar diatom *Fragilariopsis cylindrus* under different light intensities as well as different Fe availability. When algal cells were frozen into the ice, the maximum quantum yield of photosystem II (PSII) (F_v/F_m) decreased regardless of the treatments, possibly due to the damage of PSII reaction centers or high brine salinity stress suppressing the reduction capacity downstream of PSII. Gene expression of the *rbcL* gene was highly upregulated, suggesting a survival strategy for acclimating to the cold ice environment in the ice. The frozen algae within the ice showed almost the same levels of F_v/F_m regardless of the treatments. When the ice melted and the cells were exposed to high light (800 μmol photons m^{-2} s^{-1}), F_v/F_m sharply decreased, while non-photochemical quenching (NPQ) was upregulated to dissipate the excess light energy. Interestingly, the *psbA* gene encoding the D1 protein of PSII was upregulated under high Fe conditions and vice versa. These results suggested Fe repletion accelerated *de novo* synthesis of the D1 protein, but Fe starvation inhibited repair of the PSII damaged by the high light. Our results imply that Fe-starved cells cannot well regulate their photosynthetic plasticity to the environmental changes during ice melting, and would little contribute to ice-edge blooms.