Variations in the water column photosynthetic cross section for Antarctic coastal waters

Hervé Claustre[1, 2], Mark Moline[1] and Barbara Prézelin[1]

[1] Department of Ecology, Evolution and Marine Biology, University of California at Santa Barbara
[2] Laboratoire de Physique et Chimie Marines, B.P. 08 06230 Villefranche-sur-mer France.

ABSTRACT

Using a highly resolved LTER data base collected near Palmer Station, Antarctica, from 1991-1994, the variability in the column photosynthetic cross section (Ψ^*, m^2 g Chl a^{-1}) was analyzed. For the whole dataset, Ψ^* had an average value of 0.0695 m^2 g Chl a^{-1} but extreme values extended over a 50-fold range (0.009-0.488 m^2 g Chl a^{-1}). A six-fold variation in Ψ^* was observed with time of year and was strongly associated with the high seasonality in incident irradiance characteristic of these polar sampling sites. Variability in daily incident irradiance as influenced by cloudiness and variation in chlorophyll content were responsible for an additional two-fold variation in Ψ^*. Finally, the taxonomic dependency of Ψ^* was demonstrated for the first time. For identical chlorophyll content and surface irradiance, mean Ψ^* value of 0.114 ± 0.051 m^2 g Chl a^{-1} were recorded for diatom blooms and 0.053 ± 0.011 m^2 g Chl a^{-1} for cryptophyte-dominated populations. Results illustrate the validity of Ψ^*-based approaches for estimating primary production for the Southern Ocean but emphasize the need to address taxon-specific photophysiology to better estimate primary production on smaller spatio-temporal scales.

Keywords: Antarctic, marine primary production, bioptical models

1. INTRODUCTION

The column photosynthetic cross section Ψ^*, (m^2 g Chl a^{-1}) is defined as[1,2] :

$$\Psi^* = \frac{39P}{Q_{PAR}(0^+)\langle \mathrm{Chl} \rangle}$$

where the surface irradiance $Q_{PAR}(0^+)$ is expressed into its energy equivalent (kJ m^{-2} d^{-1}), P (gC m^{-2} d^{-1}) is the column integrated (down to 0.1% of $Q_{PAR}(0^+)$) primary production rates, <Chl> (g Chl a m^{-2}) is an estimate of areal chlorophyll a and the constant value of 39 corresponds to the kilojoules of chemical energy stored by the photosynthetic fixation of 1 g C.

For various trophic situations in temperate and tropical oceans, it was observed[1,3] that Ψ^* varies by ± 50 % (at one standard deviation) around a central value of 0.07 m^2 g Chla^{-1}. The relative stability of this biogeochemical index is of great hope in view of deriving primary production rates from synoptic measurements of chlorophyll (remote sensing) and estimates of surface irradiance. For the Southern Ocean, documentation of phytoplankton distribution, *in situ* rates of primary production and associated photophysiological efficiency have been generally lacking. Therefore, the accuracy of bio-optical algorithms for prediction of Antarctic primary production on different time and space scales remains uncertain and the problem of specific parametrization relevant to polar latitudes has to be addressed.

As part of the Palmer Long Term Ecological Research (LTER) program[4], a large data base of primary production, algal pigmentation, and incident irradiance was acquired over a three-year period (1991-1994) from late to early winter for a coastal Antarctic region[5]. Even though the sampling stations were in shallow waters, analyses shows that Case I water predominated for most of the samples collected and enabled us to make comparisons relevant to the high nutrient, often low biomass waters of the Southern Ocean[6]. Using this highly-resolved data set, the column photosynthetic cross section has been derived for 151 sample dates and the sources of variability have been assessed as a function of season, cloudiness, as well as phytoplankton biomass and taxonomic dominance.

2. RESULTS AN DISCUSSION

The frequency distribution of Ψ^* for the whole data set and using irradiance measurements (Figure 1A) was found to be non-normally distributed, with a median of 0.088 m^2 g Chl a^{-1} and an average of 0.109 m^2 g Chl a^{-1} ± 0.075. This average value corresponds to what is considered as an upper limit for Ψ^*[1,3]. The range of variation at one standard deviation

SPIE Vol. 2963 • 0277-786X/97/$10.00

extend over a factor 5.4 (compared to 3-fold for temperate and tropical area) and the extreme values recorded in this studies extend over a 50-fold range (0.009-0.488 m^2 g Chl a^{-1}).

If the data set is restricted to a period of two months centered around the summer solstice (removing seasonal effect) (November 21 - January 21), the frequency distribution of Ψ* (for clear sky condition, modeled using standard conditions[2], in order to remove cloudiness effect) is normal (Figure 1B): the median (0.060 m^2 g Chl a^{-1}) nearly equals the average (0.064 m^2 g Chl a^{-1} ± 0.027). The range of variation at one standard variation is now 2.5 which is below the range reported for a compilation of data from various provinces[3]. But, even with the seasonality and cloudiness removed, significant variability still exists in Ψ*. This variability is likely due to biology and to the possible variations in phytoplankton biomass and photo-physiology.

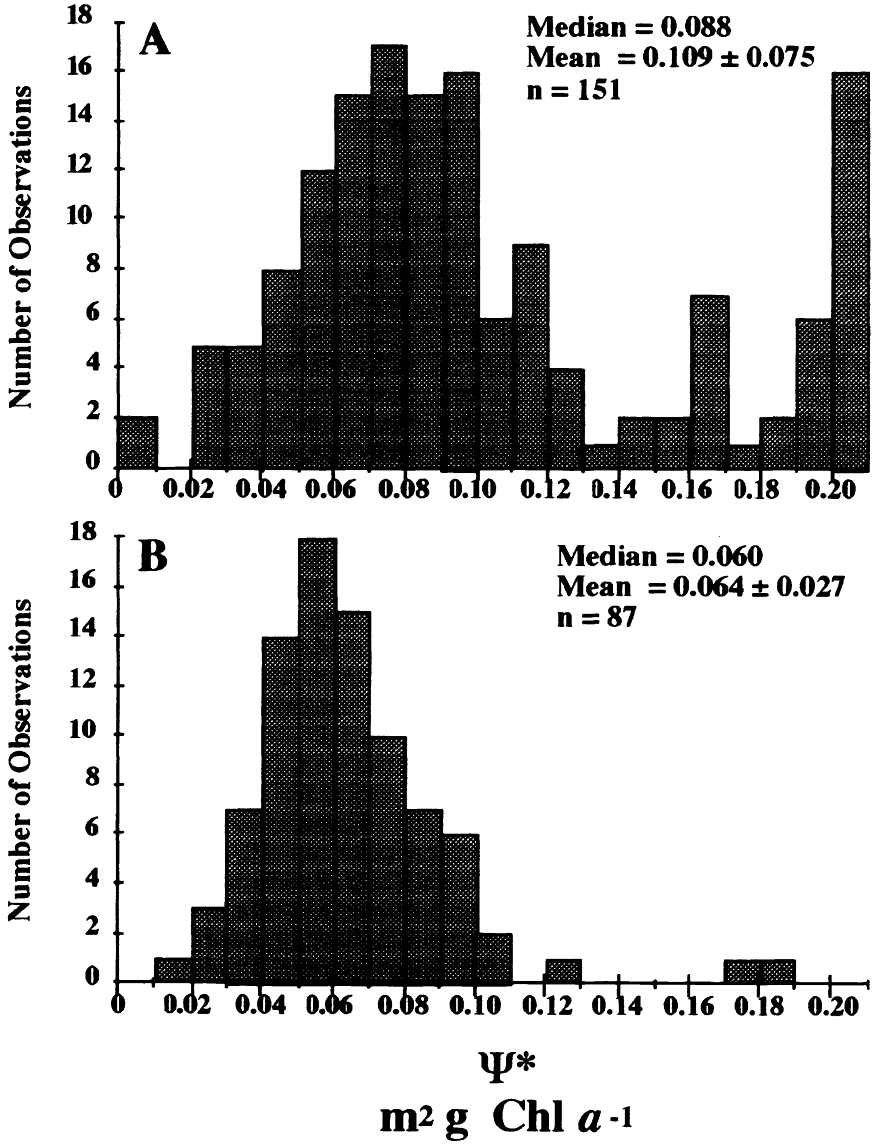

Figure 1 : Frequency distribution of Ψ* at Palmer station, Antarctica. **A** For the whole data set. **B** For clear-sky conditions only (removing cloudiness effect) and for a two-months period around the summer solstice (removing seasonal effect).

Considering all profiles where a single taxon contribute to more than 50% of the chlorophyll biomass, Ψ* (computed for clear sky conditions) for diatoms was greater than that for cryptophytes by 77 % (t-test, $p < 0.001$) and greater than that for nanoflagellates by 60 % (t-test, $p < 0.02$) (Table 1). But such comparisons suffer from the possible interference of seasonality in surface light or from some biomass effect. Therefore, the data set was restricted to the period around the summer solstice (November 21-January 21) and the samples were partitioned according to a mean chlorophyll content (Chl) threshold of 2 mg Chl *a* m^{-3}. In order to deal with quasi-monospecific populations, only those data where a single taxonomic group contribute to more than 70% of the chlorophyll biomass were considered. Using such restrictions, the data set is limited, however, it clearly shows two main results. (1) For diatom-dominated communities, when Chl increased by a factor 7 (from 1.1 to 7.3 mg Chl *a* m^{-3}) Ψ* decreased by a factor 1.7 (test t, $p < 0.02$) (Table 1). Such a reduction in Ψ* associated with increasing chlorophyll biomass is higher than expected from modeled results[2], which predict a reduction in Ψ* of only *ca.* 10 % for the same biomass range. For cryptophyte-dominated communities, the range of chlorophyll concentration investigated here is only 3 (from 1.3 to 3.9 mg Chl *a* m^{-3}) and an associated reduction of a 1.5 factor (test t, $p < 0.02$) is also observed. (2) Ψ* for diatoms was 2.15 times higher than for cryptophytes ($p < 0.001$) when Chl was lower than 2 mg Chl *a* m^{-3}, and 2 times higher when was greater than 2 mg Chl *a* m^{-3}. Therefore we can conclude that, for the same amount of chlorophyll in the water column and for the same incident irradiance, daily integrated primary production is depressed by a factor two when cryptophytes replace diatoms.

Table 1: Influence of chlorophyll concentration and phytoplankton community structure on Ψ* (for clear-sky conditions) at Palmer station, Antarctica.

TAXONOMIC GROUP		Ψ*	n
Taxonomic group contribution > 50% of <Chl>			
no Chl *a* threshold	Diatoms	0.094 ± 0.041	51
no Chl *a* threshold	Cryptophytes	0,053 ± 0.017	31
no Chl *a* threshold	Flagellates	0.059 ± 0.035	16
Taxonomic group contribution > 70% of <Chl>[1]			
< 2 mg Chl *a* m^{-3}	Diatoms	0.114 ± 0.051	6
< 2 mg Chl *a* m^{-3}	Cryptophytes	0.053 ± 0.011	13
> 2 mg Chl *a* m^{-3}	Diatoms	0.068 ± 0.020	14
> 2 mg Chl *a* m^{-3}	Cryptophytes	0.034 ± 0.013	3

[1] For the period November 21 to January 21, only (to remove the seasonal influence).

3. CONCLUSIONS

Analysis of the variability of Ψ* has highlighted the importance of incident light variations, driven by seasonality and cloudiness. The remainder of the variability (more than a factor of 2) can be explained by changes in phytoplankton composition and associated photophysiology. It was indeed very clear from this study that the water column efficiency in trapping and converting solar energy into organic matter is greater when diatoms dominate the community as compared to cryptophytes or other flagellate species. This observation is restricted to the present data set but it nevertheless emphasizes the need to account for taxonomic differences in the development of future biooptical models, if the goal is improved accuracy in primary production estimates.

4. ACKNOWLEDGMENTS

This study was supported by National Science Foundation grant DPP 90-901127 to B. B. Prézelin. H. Claustre received a NATO grant as part of his sabbatical in B. B. Prézelin laboratory.

5. REFERENCES

1. Morel, A., "Available, usable, and stored radiant energy in relation to marine photosynthesis," *Deep Sea Res.*, **25**, 675-688 (1978).
2. Morel, A., "Light and marine photosynthesis : a spectral model with geochemical and climatological implications," *Progr. Oceanogr.*, **26**, 263-306 (1991).
3. Platt, T., "Primary production of the ocean water column as a function of surface light intensity : algorithms for remote sensing," *Deep Sea Res.*, **33**, 149-163 (1986).
4. Smith R. C., K. S. Baker, W. R. Fraser, E. E. Hofman, D. M. Karl, J. M. Klinck, L. B. Quetin, B. B. Prézelin, R. M. Voss, W. Z. Trivelpiece, and M. Vernet, "The palmer LTER : A long-term ecological research program at Palmer Station, Antarctica," *Oceanography*, **8**, 77-86 (1996).
5. Moline, M.A., and B. B. Prézelin, "Palmer LTER 1991-1994: Long-term monitoring and analyses of physical factors regulating variability in coastal Antarctic phytoplankton biomass, *in situ* productivity and taxonomic composition over subseasonal, seasonal and interannual time scales," *Mar. Ecol. Prog. Ser.*, in press.
6. Claustre, H., Moline, M.A., Prézelin, B.B., "Variability in the column photosynthetic cross section for Antarctic coastal waters," *J. Geophys. Res.*, in press.