# PHYTOPLANKTON PHOTOSYNTHETIC POTENTIAL IN COASTAL ZONES AROUND THE WORLD

## POTENCIAL FOTOSINTÉTICO DEL FITOPLANCTON EN LA ZONA COSTERA MUNDIAL

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## I. INTRODUCTION

Solar electromagnetic radiation is the fundamental source of energy that drives Earth's climate and sustains life. Primary biological production of the biosphere depends on photosynthesis, which uses solar energy to transform water and carbon dioxide into organic compounds that store chemical energy. This process in aquatic ecosystems is mostly carried out by phytoplankton, unicellular organisms that move passively in the water column, and which play a pivotal role in global biogeochemical cycles and food web dynamics [1]. Solar electromagnetic radiation in the wavelength range 400–700 nm is responsible for the bulk of photosynthesis, and it is called photosynthetically active radiation (PAR). Ultraviolet radiation (UVR, 280−399 nm) is generally considered an inhibitor of the process. These energetic wavelengths affect cellular DNA, impair photosynthesis, enzyme activity and nitrogen incorporation, bleach cellular pigments and inhibit motility and orientation [2].

Climate change can alter the exposure of aquatic ecosystems to UVR by influencing the Earth system processes that affect ozone depletion as well as changes in aquatic UVR absorbing substances such as colored dissolved organic matter (CDOM). This one controls the penetration of UVR into water bodies, but it is photodegraded by solar UVR [3].

Given their global importance, coastal marine environments are a major focus of concern regarding the potential impacts of anthropogenic climate change [4]. Coastal zones vary tremendously in their optical properties and have a lower transparency than open ocean waters due to the runoff of silt and dissolved organic carbon from shores. On the other hand, there have been fewer studies of temperate and tropical coastal seas specifically, perhaps because the assumption has been made that ozone depletion is only a problem for polar seas, and that the ozone hole is an Antarctic problem [5].

The aim of this work is to do a quantitative assessment of the phytoplankton photosynthetic potential in coastal zones around the world, using a (generic) optical classification of coastal waters, and considering the UVR inhibition.

We quantified the phytoplankton photosynthetic potential for the illuminated layers of coastal areas (50 $m$) taking into account the global average depth of this zone [6]. We consider three representative latitudes proxies for equatorial ($0^o$), tropical ($30^o$) and subarctic ($60^o$) regions. The annual average solar spectral irradiances at these latitudes for PAR and UVR were used. In all cases cloudless skies were assumed. It was used Jerlov's optical coastal water classification [7], selecting types C1 (clearest) and C9 (darkest).

To compute the photosynthesis rates $P$ at depth $z$ (normalised to saturation rates $P_s$), we use a model for photosynthesis, typically employed with phytoplankton assemblages with good repair capabilities of UVR induced damages [8]:

$$\frac{P(z)}{P_s} = \frac{1 - \exp(-E_{PAR}(z)/E_s)}{1 + E^*_{UV}(z)}, \tag{1}$$

where $E_{PAR}(z)$ and $E^*_{UV}(z)$ are the irradiances of PAR and UVR at depth $z$ calculated following the procedure of [9].

The parameter $E_s$ accounts for the efficiency with which the species uses PAR: the smaller its value, the greater the efficiency. We checked the two extremes, highest ($E_s$ = 2 $W/m^2$) and lowest ($E_s$ = 100 $W/m^2$) efficiency, such as in [9].

To consider more accurately the inhibitory effect of UVR on photosynthesis we used two biological weighting functions (BWF): one for temperate [10] and other for Antarctic phytoplankton [11]. These BWF account for both DNA damage and photosystem inhibition, resulting in whole-cell phytoplankton photosynthesis inhibition. The first BWF was used to calculate photosynthetic potential in equatorial and tropical zones, while the last one was used for subarctic zones.

This study has shown that coastal phytoplankton assemblages can be sensitive to high levels of UVB (280−319 $nm$) and UVA (320−399 $nm$) radiations in the first five meters of the water column approximately, where the photosynthetic potential can be depressed, but without total photoinhibition ($P/P_s = 0$).

UVR effects in aquatic ecosystems are distinguished by strong vertical gradients, so that most effects occur near the surface. This radiation is quite rapidly attenuated in the first meters of the water column and therefore can not penetrate to deeper water. On the other hand, PAR attenuation in deeper water has an important factor in the fall of photosynthetic potential. Considering these two restrictions, the highest photosynthetic potential will be reached at some intermediate depth, where the optimal balance UVR–PAR is achieved.

The exact depth of maximum photosynthetic potential depends on radiation intensity (latitude), optical water properties and sensitivity of the species to both UVR and PAR (Table 1). The highest photosynthetic potential is 100 % and it is reached by highly efficient species ($E_s$ = 2 $W/m^2$) in clearest coastal waters (C1) at both equatorial ($0^o$) and tropical ($30^o$) regions.

Table 1. Highest photosynthetic potentials reached at corresponding depths (m) between parentheses for generic coastal water columns of 50 m depth with different optical properties.

| Latitude | $E_s$ = 2 $W/m^2$ | | $E_s$ = 2 $W/m^2$ | |
|---|---|---|---|---|
| | C1 | C9 | C1 | C9 |
| $0^o$ | 100 (10-15) | 99.6 | 78.6 (5) | 41.5 |
| $30^o$ | 100 (10-15) | 99.0 | 72.3 (5) | 45.8 |
| $60^o$ | 99.9 (10) | 90.8 | 47.2 (5) | 27.1 |

Latitude determines the average annual irradiance at sea level, which diminish as one move from the Equator towards poles. However, our calculations showed similar potential for photosynthesis in equatorial and tropical regions (Figs. 1a and 1b). This can be explained by the fact that there is more PAR in the Equator, but also more (inhibitory) UVR, and some sort of compensation exists. For subarctic zones smaller photosynthesis potential was obtained (Fig. 1c). Actually, the sea waters of the $60^o$ latitude are usually rich in nutrients, yet, except in isolated regions, phytoplankton normally are scarce. Annual primary productivity is extremely low and it has frequently been suggested that it is limited by light, rather than by nutrients [12].

Table 2. Highest photosynthetic potentials reached at corresponding depths (m) between parentheses for generic coastal water columns of 50 m depth with different optical properties.

| Latitude | $E_s$ = 2 $W/m^2$ | | $E_s$ = 2 $W/m^2$ | |
|---|---|---|---|---|
| | C1 | C9 | C1 | C9 |
| $0^o$ | 67.7 | 14.7 | 21.9 | 4.7 |
| $30^o$ | 65.8 | 14.8 | 20.2 | 5.0 |
| $60^o$ | 55.7 | 11.9 | 11 | 2.9 |

As expected, in all scenarios the most efficient species assimilating PAR showed the highest photosynthetic potential, while the less efficient ones got minor potential (Fig. 1). Most efficient species show a relatively better adaptation to light scarcity in subarctic regions (their potentials are smaller in around 20 %); while for less efficient organisms rates are smaller in 40 – 50 % (Table 2).

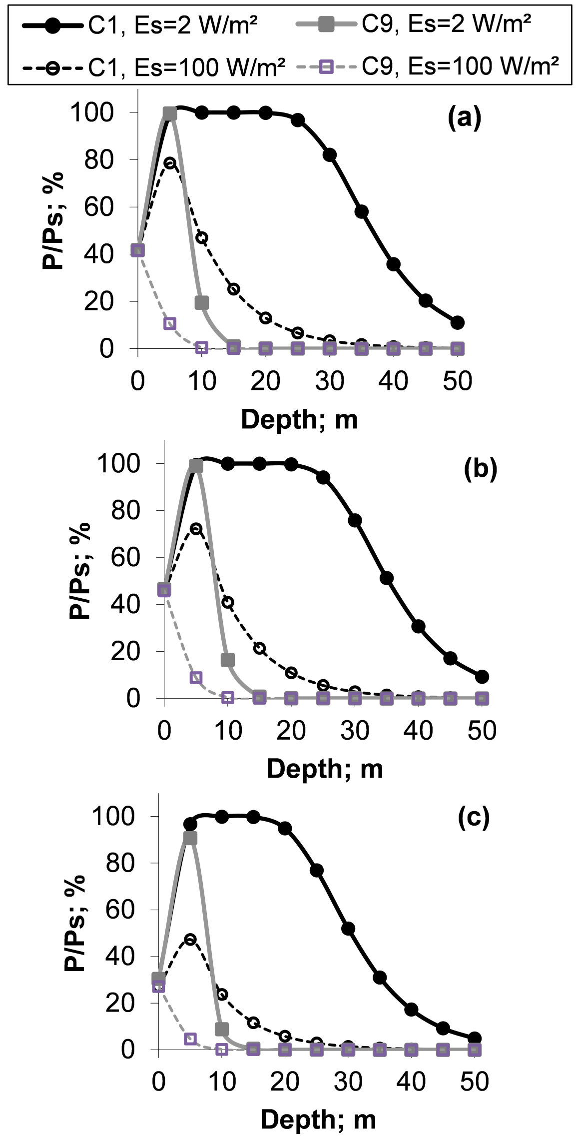


Figure 1. Photosynthetic potential for (a) $0^o$, (b) $30^o$ and (c) $60^o$ latitude in different coastal optical water types.

In conclusions, UVR can stress photosynthetic process in the first five meters of the water column without total photoinhibition. In all scenarios the potential for clearest waters was around five times greater than for the darkest waters. Also, and interesting enough, for the same water type photosynthetic potentials in equatorial and tropical regions were approximately equal. Subarctic regions showed smaller potentials, being the less efficient organisms more affected.

We point out that this work is from the point of view of Ocean Optics. Further modeling would imply the inclusion of nutrients and probably other environmental variables to obtain a more accurate picture.

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