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Estimation of Primary Production from the Light Absorption of Phytoplankton and Photosynthetically Active Radiation in the South China Sea

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1.Abstract

Phytoplankton absorption coefficient (a_{ph}) has been considered a better and reliable bio-optical proxy for estimating marine PP than chlorophyll a. A PP model derived from $a_{ph}(443)$ and photosynthetically active radiation (PAR) was built, based on a dataset collected during 2019 in the South China Sea (SCS) (including estuarine, coastal and offshore waters). There was a significant log-linear relationship between PP and the production of $a_{ph}(443)$ and PAR ($a_{ph}(443)\times$PAR) with Adj. R^2 being 0.64. The model was validated by K-fold cross-validation and an in situ dataset collected in 2018 in the SCS basin. Results showed that, the model had good generalisation performance and could be applied to various water environments. To explore the influence of phytoplankton communities on the model, the HPLC method and the characteristic pigment method were used to quantify pigments and identify dominant phytoplankton species, respectively. The concentration of photosynthetic carotenoids (PSCs) and photoprotective carotenoids (PPCs) per unit total chlorophyll a was used to determine the physiological state of dominant phytoplankton. The dataset was divided into five dominant phytoplankton clusters, of which the Diatoms-dominant cluster, the Haptophytes-dominant cluster and the Prochlorococcus-dominant cluster were studied separately for their impact on our model. Most samples in Diatoms-dominant and Haptophytes-dominant clusters were considered to be in the light limited stage, their PP values showed an increasing trend as the increasing $a_{ph}(443)\times$PAR. However, Prochlorococcus-dominant samples might show the photoinhibition, and the PP values showed a decreasing trend with the increasing $a_{ph}(443)\times$PAR. This phenomenon was considered to be related to their bio-optical characteristics. The predictive power of our model is related to the photophysiological state of the dominant phytoplankton in the dataset, It is suitable for samples in light limitation, but may not perform well if there is massive photoinhibition. Our study provides guidance for the development of phytoplankton-specific a_{ph}-based PP models.

2.Method

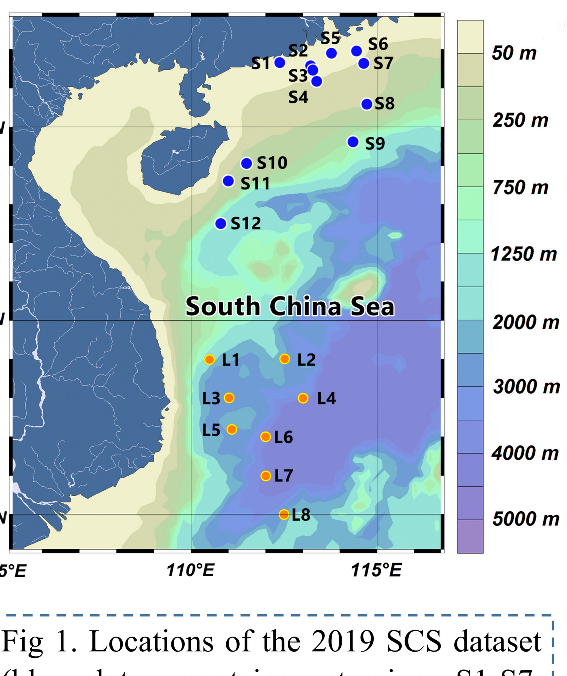


Fig 1. Locations of the 2019 SCS dataset (blue dots, contains estuarine: S1-S7, ≤100m, and offshore: S8-S12, >100m waters) and the 2018 SCS dataset (orange dots, L1-L8, >1500m).

In situ sampling:

1. Primary production measurements

PP was determined through on-deck incubation at five light penetration depths (100%, 56%, 22%, 7%, and 1% of the surface PAR) at each station (49 samples in the 2019 SCS dataset and 28 samples in the 2018 SCS dataset)

2. $a_{ph}(\lambda)$ and Phytoplankton pigments

Pigments were quantified using high-performance liquid chromatography (HPLC)

3. PAR and temperature

A Profiler II underwater spectral profiling instrument was used to measure the downwelling irradiance of the free-fall water column profile; Temperature profiles were determined using CTD.

3. Results

3.1 Model building

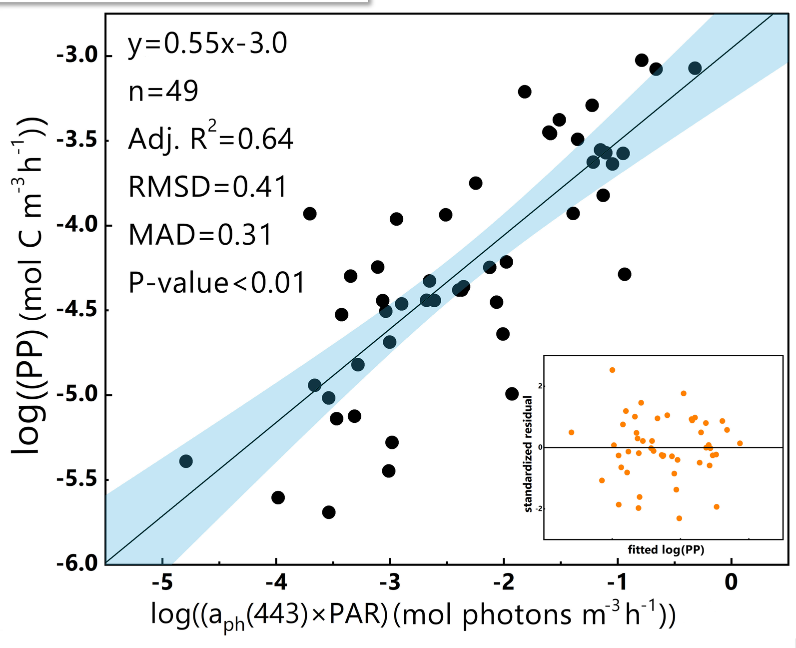
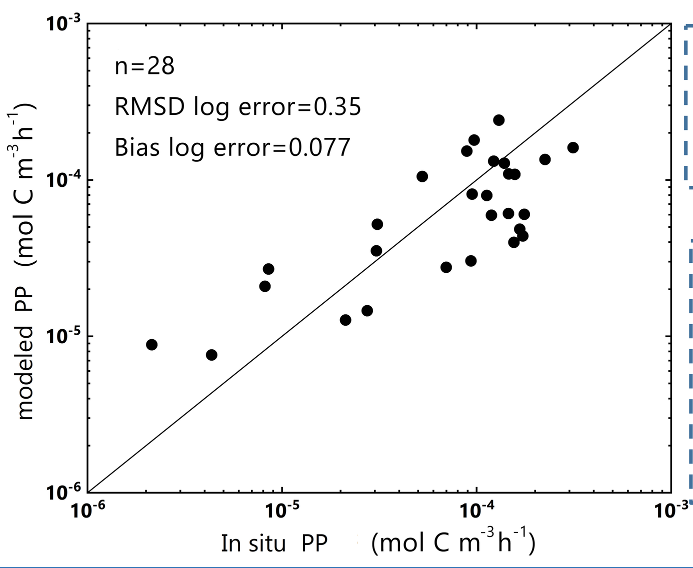


Fig. 2 **Log-linear regression of PP and a_{ph} (443)×PAR in the euphotic zone** for the 2019 SCS dataset. The dark line represents the linear regression, and the blue band represents the 95% confidence interval. The residual plot is in the bottom-right corner. The equation, number of data points (n) and some statistical parameters are shown in the upper-left corner.

3.2 Verified the log-linear PP model by the in situ dataset & K-fold cross-validation

When K=10, the standard deviation of the mean MSD is low (0.13), and the mean MSD from cross-validation (0.18) is similar to that of the 'log-linear PP model' (0.17). The Adj.R^2 between the predicted values and real values from cross-validation (0.56) is also similar to that of the log-linear PP model (0.64).



This model can not only be applied to the data collected in estuarine, coastal, and offshore areas but also be available for the data collected in the SCS basin.

Fig 3. Plot of PP obtained from the log-linear PP model and in situ PP from the 2018 SCS dataset (in log-scale). y = x is represented by the dark line. Number of data points (n) and some statistical parameters are shown in the upper-left corner.

4. Discussion

4.1 Bio-optical characteristics of different dominant phytoplankton cluster

	Diato-	Hapto-	Pro-
Average PAR	0.86	0.035	0.79
Range of PAR	[0.0062, 3.8]	[0.0019, 0.096]	[0.080, 1.9]
Average $a_{ph}(443)$	0.052	0.019	0.0061
Range of $a_{ph}(443)$	[0.011, 0.13]	[0.0084, 0.026]	[0.0041, 0.0097]
Average PP	3.5×10^{-4}	1.4×10^{-5}	4.0×10^{-5}
Range of PP	[3.6×10^{-6}, 9.4×10^{-4}]	[2.0×10^{-6}, 3.6×10^{-5}]	[1.0×10^{-5}, 5.7×10^{-5}]
Average TChla	1.2	0.40	0.095
Average PPC/TChla	0.20	0.20	0.92
Average PSC/TChla	0.65	0.92	0.34

4. Discussion

4.2 Separate analysis of the different phytoplankton dominant clusters

Table 1. Statistical results for the bio-optical parameters of each dominant phytoplankton cluster. TChla = Chla+DVChla; PPC = violaxanthin+ diadinoxanthin+ alloxanthin+ zeaxanthin+ lutein+ (β-carotene); PSC = peridinin+ (19′-but-fucoxanthin)+ (19′-hex-fucoxanthin)+ fucoxanthin. Units:PAR (mol m^{-2} h^{-1}); a_{ph} (443) (m^{-1}); PP (mol m^{-3} h^{-1}); TChla (mg m^{-3}).

	Pro	Hapto	Diato
n	12	10	15
Equation	y=-0.24x-5.0	y=0.49x-3.4	y=0.59x-2.7
Adj. R^2	0.22	0.40	0.68
P-value	>0.05	<0.03	<0.01

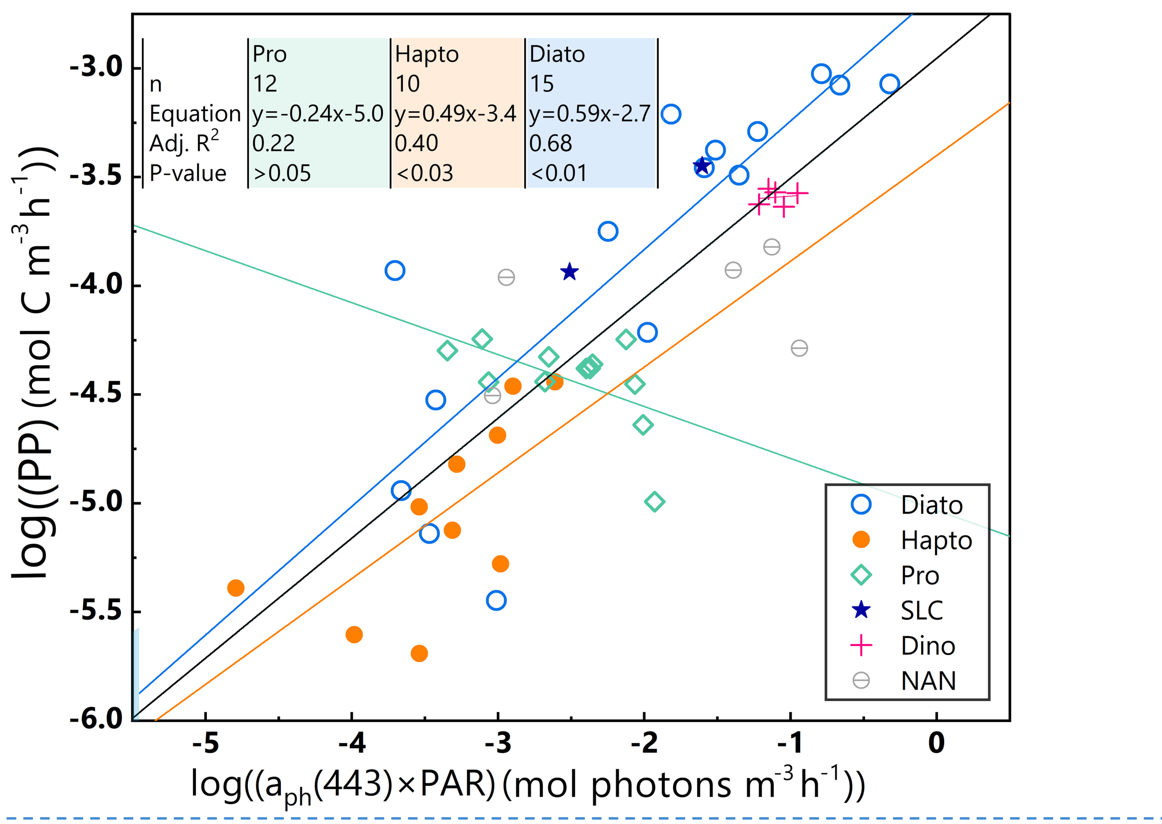


Figure 4. Different dominant phytoplankton samples are represented by various colours and shapes.black line = whole dataset, blue line = Diato-dominant cluster, orange line = Hapto-dominant cluster, green line = Pro-dominant cluster.

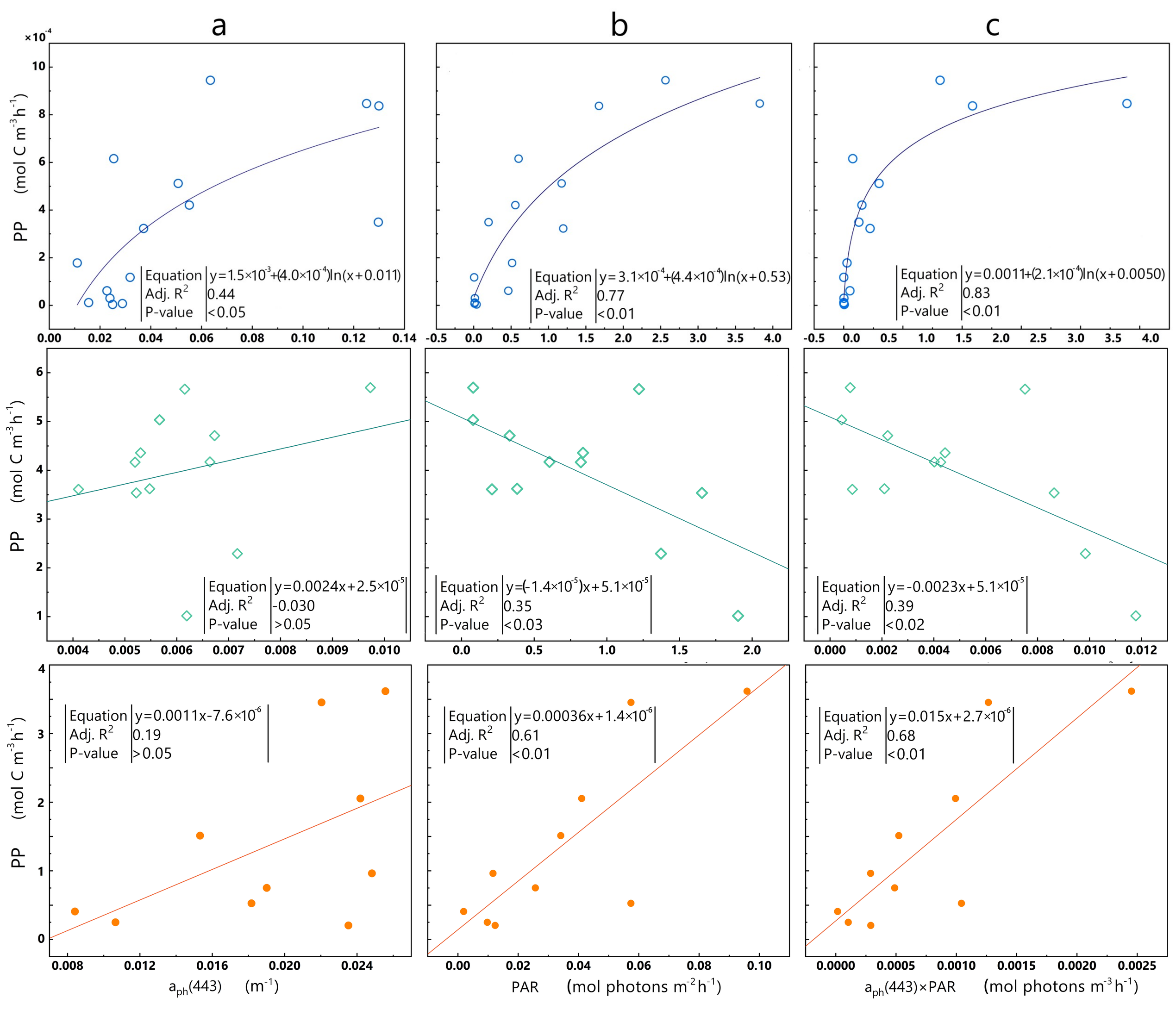


Figure 5-7. Relationships between a_{ph} (443) and PP, PAR and PP, and $a_{ph}(443)\times$PAR and PP in the euphotic zone for three clusters.

4.3 The photophysiological state of different clusters

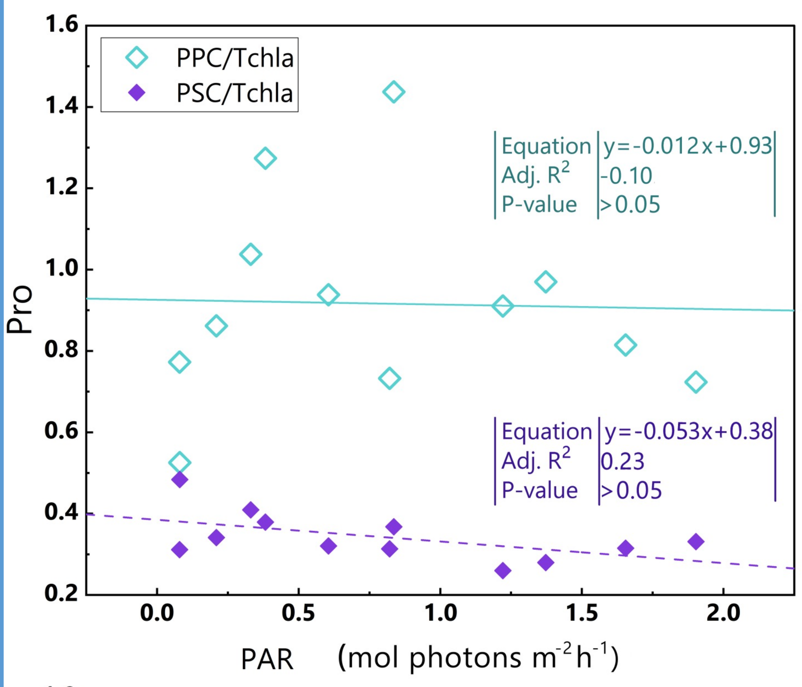


Figure 8. Relationships between PAR and PPC/TChla, PAR and PSC/TChla in the euphotic zone for the Pro-dominant cluster in the 2019 SCS dataset. Linear regression for PAR and PSC/TChla (purple dotted line) and linear regression for PAR and PPC/TChla (green line). Equations and some statistical parameters are also shown (green text for green line, purple text for purple dotted line).

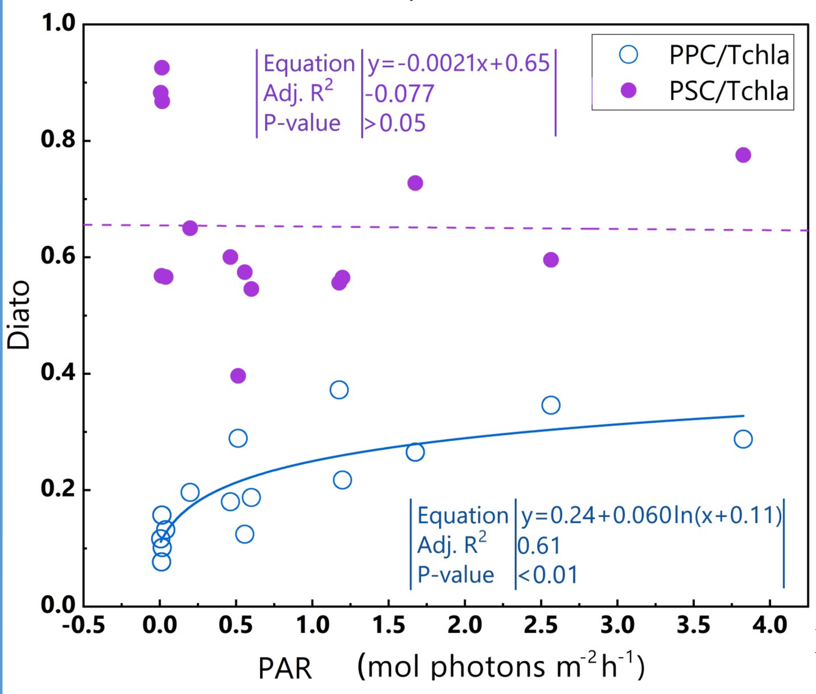


Figure 9. Relationships between PAR and PPC/TChla, PAR and PSC/TChla in the euphotic zone for the Diato-dominant cluster in the 2019 SCS dataset. Linear regression for PAR and PSC/TChla (purple dotted line) and log regression for PAR and PPC/TChla (blue line). Equations and some statistical parameters are also shown (blue text for blue line, purple text for purple dotted line).

Diato-dominated clusters and Hapto-dominated clusters are light-limited, while Pro-dominated clusters are light-suppressed

5. Conclusion

- A regional a_{ph} (λ)-based PP model (the log-linear PP model) was built based on an in situ dataset collected during 2019 in the SCS. The results of the statistical analysis, K-fold cross validation and in situ data validation show that, this log-linear PP model has satisfactory predictive capability and that the model is applicable not only to estuarine, coastal and offshore datasets but also to basin datasets.
- The predictive power of the log-linear PP model is related to the photophysiological state of the phytoplankton in the dataset. In the real marine environment of the SCS, there are different kinds of dominant phytoplankton assemblages, and these phytoplankton may be in different physiological states, which may include light-saturated, light-inhibited, and light-limited simultaneously. If large-scale photoinhibition in the dataset is present (e.g., the Pro-dominant cluster above), the log-linear PP model cannot obtain accurate prediction values, but if the samples in the dataset were in the light-limited state (as in the Hapto-dominant cluster and Diato-dominant cluster above), the log-linear PP model can yield satisfactory predictions of PP.
- This study lays the foundation for the establishment of phytoplankton-specific primary productivity models in sea areas dominated by different phytoplankton.