Remote sensing of phytoplankton photosynthetic rates and production from measurements of ocean colour.

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The most widespread remote sensing algorithms for the interpretation of ocean colour data (Rrs, l) have only one variable, Chlorophyll-a concentration (Chla) and use a band ratio at 2 wavelengths (Rrs, 490, 555 nm). Chla absorbs light in the blue (400 to 470 nm) and these algorithms work only because accessory pigments, mostly the photosynthetic carotenoids (PSC), co-exist and co-vary robustly with Chla over most ocean provinces (marine ecosystems). The inter-province variance of the Chla to PSC is the main source of error in global phytoplankton pigment, band-ratio algorithms. Algorithms for the determination of primary production from ocean colour data are relatively simple and most use Chla as the principal variable. Chla is a crucial component of the photosynthetic apparatus, though a variable fraction of only 1 in 200 to 1 in 600 of Chla-molecules are part of Photosystem (PS) I or II; the remainder "antennae Chla" are part of the light-harvesting complex along with the photosynthetic carotenoids. Since all the photons absorbed by the photosynthetic pigments contribute to photosynthesis, the total absorption of light by phytoplankton ap(l) is the most appropriate variable for the determination of primary production. Chla, as a measure of the "steady-state biomass", at best might be related to net production. Because of these uncertainties, the use of Chla as a surrogate for productivity, compounds the errors in the determination of primary production from remotely sensed measurements of ocean colour (Rrs, l). Conceptually, ocean colour (Rrs), an inverse function of the light absorbed, should be functionally related to primary production, a direct function of the light absorbed, and in theory phytoplankton production should be derivable directly from Rrs. We have analysed data on phytoplankton pigment composition from the equatorial Pacific Ocean (IronEx II), the Southern Ocean (SOIREE), the Atlantic Ocean (Atlantic Meridional Transect; AMT) and European shelf seas and derived the relationships to photosynthetic quantum efficiency (PQE, Fv/Fm) determined by Fast Repetition Rate Fluorometer (FRRF). The Chlorophyll a to total pigment fraction (Chla/Tpig) has been shown to be significantly correlated to PQE, both generally and more significantly, within provinces or within seasons. The inference is that in the enrichment experiments (IronEx II and SOIREE) plants when stimulated to grow, synthesise Chla in preference to other accessory pigments and decrease Chla synthesis relative to other pigments when stimulation wanes. A similar mechanism probably underlies the relationship between PQE and Chla/Tpig in the natural ecosystems of the Atlantic Ocean and the shelf seas. Evidence from laboratory culture experiments is consistent with these observations. We conclude that Chla is maintained at the level needed to sustain the maximum growth rate in the environment. In other words, Chla concentration is self-regulating, in response to the limitations imposed by other growth substrates.

We show that the Chla/Tpig ratio is a proxy for Chla/Carbon ratio and may also be a proxy for cell nutritional status, both of which have variances in natural ecosystems that are related to photosynthetic activity and productivity. $PQE \cdot PAR \cdot \sigma_{PSII}$ is proportional to production (σ_{PSII} is the effective absorption cross-section for PSII). An inference is that Chla/Tpig as a proxy for PQE may be a significant parameter in models of gross primary production and for dynamical processes such as the drawdown of CO_2.

Chla has a unique deep blue absorption spectrum (centred at 443 nm), differing markedly from the other accessory pigments (mainly carotenoids) which absorb blue-green light (centred at 490 nm). We show that the Chla/Tpig fraction has a distinct optical signature, detectable in remotely sensed observations of ocean colour, providing a bio-optical algorithm for PQE and the other proxies.