

Table 3 Photon requirements of photosynthesis in marine algae grown, and measured, at close to present day atmospheric concentrations of carbon dioxide

Organism, conditions of growth and measurements	Quantum requirement, absorbed mol photon per mol carbon or per mol oxygen	References ^a
<i>Thalassiosira pseudonana</i> and six other species not marine microalgae, all with CCMs	7.79–17.2 mol absorbed photons per mol carbon assimilated in gross photosynthesis at intervals during exponential growth, using the mean of three parallel batch cultures of <i>Thalassiosira pseudonana</i> . Mean value of 10.5 mol absorbed photons absorbed photons per mol carbon assimilated in gross photosynthesis from regression of mol absorbed photons per mol carbon assimilated, with $r^2=0.994$. 13.4–24.9 mol absorbed photons per mol carbon assimilated in gross photosynthesis during exponential growth in three parallel cultures of six other species of marine microalgae	Welschmeyer and Lorenzen (1981)
<i>Phaeodactylum tricornutum</i> (with CCM) grown with nitrate as nitrogen source; values on a carbon basis are obtained by assuming a Redfield Ratio for the C:N by atoms of 6,625. Oxygen initially 20 % of air equilibrium, but this alters rates by less than 10 %	7.41 ± 1.25 (standard deviation, $n = 9$) mol absorbed photon per mol oxygen produced in gross photosynthesis; approximately 9.6 ± 1.6 on a carbon basis	Geider et al. (1985, 1986)
Two green, two brown and two red marine macroalgal species, all with CCMs; two red marine macroalgal species lacking CCMs. Photon requirement values are reported on spectral basis; values cited are those at the wavelength giving the lowest photon requirement. Action spectra were based on measurements on at least five individual algae. Absorbance of whole thalli used in photon requirement estimates were measured on single thalli (replicate absorbances where measured had 55 % confidence limits of 5–10 %). Spectral photon requirements are cited with 95 % confidence limits of 5–10 %	7.8–18.0 mol photons absorbed by the thallus per mol oxygen produced for the six species with CCMs 9.7, 10.2 mol photons absorbed by the thallus per mol oxygen produced for the two species lacking CCMs With a C:N atomic ratio of 18, the values for mol photons absorbed by the thallus per mol carbon are 8.7–20 for the algae with CCMs, and 10.8 and 11.3 for the algae lacking CCMs	Lüning and Dring (1995), Maberly (1990), Maberly et al. (1992), Johnston et al. (2001), Raven et al. (2002), Gillies et al. (2012), Atkinson and Smith (1983) for C:N atomic ratio
One green, two brown and two red marine macroalgal species, all with CCMs. Values quoted are for photons absorbed by photosynthetic pigments, not total absorption by the thallus. In the cases where 95 % confidence limits are cited it appears that 10–14 thalli were used (p. 55 of Markager 1993)	All values in mol photons absorbed by photosynthetic pigments in the thallus per mol carbon assimilated in gross photosynthesis. Values with estimates of variance range from 8.4 ± 0.7 to 9.4 ± 2.3 , where the variances are 95 % confidence limits. Individual values (so no variance) range from 9.4 to 12.7	Markager (1993), Maberly (1990), Johnston et al. (2001), Maberly et al. (1992), Raven et al. (2002)

^a References to Maberly 1990, Maberly et al. (1992), Johnston et al. (1992), Raven et al. (2002), Marconi et al. (2011) and Gillies et al. (2012) provide evidence as to the presence or absence of CCMs in the macroalgae used for quantum yield measurements by Lüning and Dring (1995) and Markager (1993)