

Supplement of Biogeosciences, 11, 4881–4895, 2014  
<http://www.biogeosciences.net/11/4881/2014/>  
doi:10.5194/bg-11-4881-2014-supplement  
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*Supplement of*

## **Flexible C : N ratio enhances metabolism of large phytoplankton when resource supply is intermittent**

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# 1 Supporting information

## 1.1 Intermittence sensitivity

The light environment experienced by phytoplankton can be highly stochastic due, for example, to changes in cloud cover, Langmuir circulation, and deep convection. Furthermore, small scale nutrient patchiness can cause intermittent exposure to nutrient replete conditions, followed by relative nutrient scarcity. Our aim is to mimic the effects of these physical processes on phytoplankton resource exposure, and thus metabolic state, without using overly complex models of ocean mixing. In the main article we assumed light and nutrient variability may be idealized with simple ‘top-hat’ functions of PFD variability. Here, we test the robustness of the results presented in the main paper, by considering different types of intermittence in photon flux density (PFD) and nutrient supply.

### *Sensitivity 1*

In the main article we assumed that phytoplankton cells make one visit to the euphotic zone, where they remain for the duration of the photophase, until they sink or are transported to depth. To simulate scenarios in which multiple visits to the euphotic zone are possible, PFD exposure was constrained as follows. Let  $h$  equal the period that cells are in the euphotic zone. Furthermore, let  $\bar{h}$  equal the time spend in the dark. Multiple photophases of duration  $h$  were modeled with:

$$E(t) = \begin{cases} 200 & \text{if } \frac{\text{mod}(t \cdot 86400, h + \bar{h})}{h + \bar{h}} \leq \frac{h}{h + \bar{h}} \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Where  $h$  was fixed at 3600 seconds (i.e. one hour), and  $\bar{h}$  was allowed to vary in the range [3600, 82800]. See figure 1 for a graphical illustration of this treatment of PFD variability.

We accounted for the possibility that organisms may pass in and out of small scale nutrient patches by applying analagous, idealized step changes in the ambient substrate concentration:

$$S(t) = \begin{cases} 1 & \text{if } \frac{\text{mod}(t \cdot 86400, h + \bar{h})}{h + \bar{h}} \leq \frac{h}{h + \bar{h}} \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

### *Sensitivity 2*

In the main article, variation in photophase was only considered within a single day. In reality, once cells disappear from the euphotic zone, it could be a matter of days until they return to the surface. We therefore also conducted a sensitivity to account for the possibility of much slower dynamics. In this case, PFD was modeled with:

$$E(t) = \begin{cases} 200 & \text{if } 0 < 7t \leq \rho \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

The factor 7 in the above equation is included to represent cells residing in the euphotic zone for some fraction of a single week. When  $\rho$  is equal to zero, cells are in complete darkness for all seven days of the experiment. When  $\rho$  is equal to 7, cells are exposed to saturating irradiance all the time. Thus, when  $\rho$  is varied within the range  $[0, 1]$ , the *average* PFD ranges from 0 to 200  $\mu\text{mol photons m}^{-2}\text{s}^{-1}$ .

We accounted for the possibility that organisms may pass in and out of small scale nutrient patches by applying analogous, idealized step changes in the ambient substrate concentration:

$$S(t) = \begin{cases} 1 & \text{if } 0 < 7t \leq \rho \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

## 1.2 Results and Discussion

Light and nutrient intermittency influences the size dependence of growth rate, even when different assumptions are made regarding the nature of that intermittency (Figs 2 and 4). When cells are assumed to make multiple trips to the euphotic zone (Fig. 1), large cells with the capacity for carbon storage benefit from a higher average daily growth rate than smaller organisms, unless the ambient substrate concentration is low enough for diffusion limited uptake to favor smaller cells with high surface area to volume ratio (Fig 2b,c). The benefit of storage is greatest when there are relatively few trips to the euphotic zone (i.e. the left contour region in Fig 2b,c). As more and more trips are allowed (i.e. increasing average PFD in Figs 2b,c), cells become less and less dependent on energy reserves to fuel growth. Eventually, cells spend a large enough proportion of time at high PFD, that maximum growth rate determines average daily growth rate, which in the case of *S. costatum* and *P. marinus* (SS120), confers an advantage to the diatom.

When there are prolonged periods of resource saturation and deficiency (Figs. 3, 4), the qualitative relationships discussed above and in the main text still hold. Interestingly, more prolonged exposure to nutrient abundance leads to relatively high growth rates of large cells, even when the average substrate supply is relatively low (compare the position of the black line in Fig. 4c of this supporting information, to the comparable contour plot in the main paper). Furthermore, there are more compelling benefits to being large when the photophase is relatively long (compare Fig. 4b of this supporting information, to the comparable contour plot in the main paper). Why do more prolonged intermittence periods appear to influence the ratios of average daily growth rate between *S. costatum* and *P. marinus* (SS120), even when the overall proportion of time spent in the different conditions is unchanged?

When model organisms are exposed to abundant nutrient supply after a period of starvation, their growth rate is transiently constrained by  $V_{max}$  (i.e. the maximum uptake efficiency). Eventually, the capacity for growth primarily depends upon their internal ability to synthesize proteins and other functional

apparatus. Small cells have higher  $V_{max}$  than large cells due to higher surface area to volume ratio, and thus deal with the transition relatively effectively. Thus, multiple transitions in and out of nutrient abundance (see Fig. 2 and the corresponding Fig. in the main article) are in a sense quite favourable for small organisms, even though they are of course restricted by storage capacity. Because *S. costatum* has a much higher maximum growth rate than *P. marinus* (SS120), more prolonged periods of growth close to the maximum achievable value leads to an even greater advantage in terms of growth rate averages (Fig. 4).

A similar argument can be used to explain the influence of prolonged photophase on growth rates. *S. costatum* has a growth rate nearly double that of *P. marinus* (SS120). Thus, when  $P_{max}$  is comparable between organisms (see Table 1 in the main paper), but *S. costatum* has a much higher maximum growth rate than *P. marinus* (SS120), the diatom has the greatest advantage when growth is constrained by  $\mu_{max}$  and not  $P_{max}$ .

In conclusion, even though there are some subtle differences in growth rates using different assumptions regarding the intermittence of resource availability, variable resource supply confers an advantage to large cells with flexible C:N ratios.

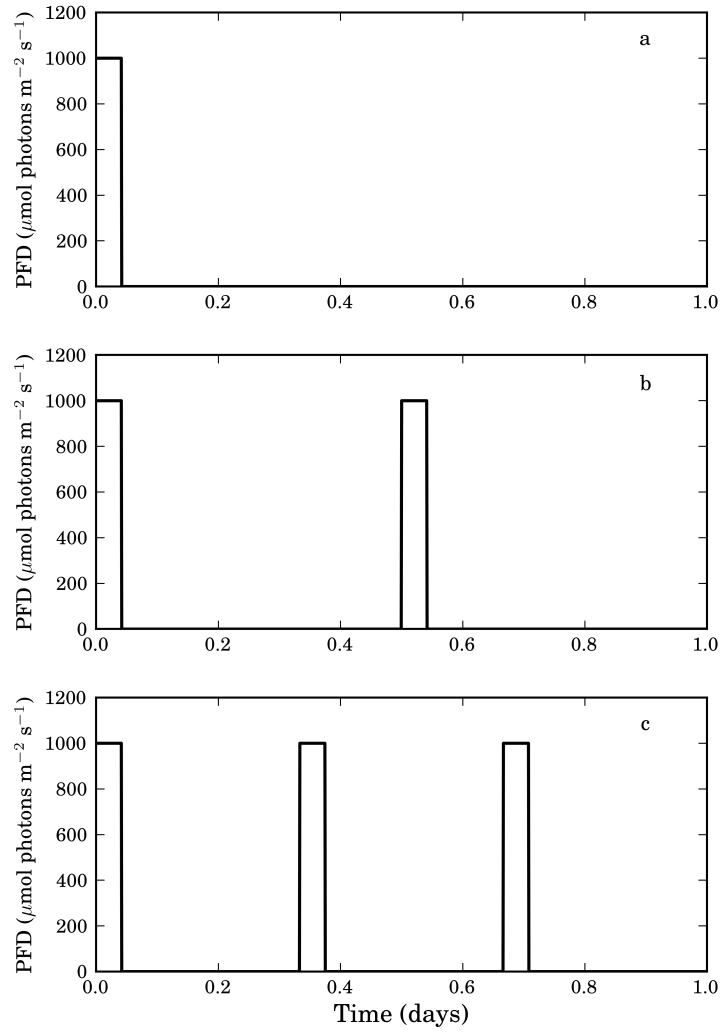


Figure 1: Graphical illustration of the first sensitivity case (equation 1). In each case,  $h$  was set constant and equal to one hour. Each period spent in the dark ( $\bar{h}$ ) was 23 hours, 11 hours and 7 hours, for panels (a), (b) and (c) respectively.

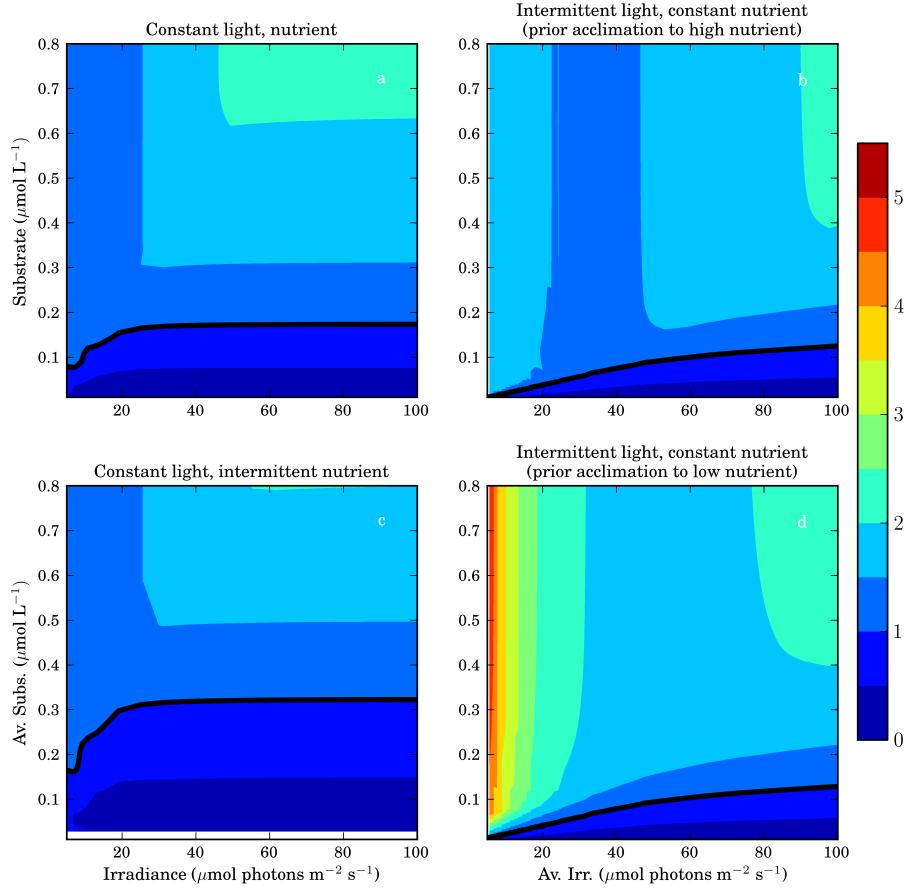


Figure 2: Sensitivity of the results presented in the main text to scenarios in which organisms experience multiple transitions in and out of resource saturating conditions. Contours are the ratio of *S. costatum* to *P. marinus* (SS120) average daily growth rate in a range of PFD and nutrient conditions. Hot colored regions indicate *S. costatum* should have an advantage in terms of average daily growth rate. Cool colored regions corresponding to values less than unity indicate SS120 should grow faster. In each case the thick black line shows where both organisms have equal growth rates. a) constant light, constant nutrient conditions. b) Constant nutrient; PFD ‘switched’ according to equation 1. c) Constant PFD; nitrogen supply ‘switched’ between 1 and 0  $\mu\text{mol L}^{-1}$ , again according to equation 2. d) Same experiment as in panel (b), this time modeled organisms were ‘acclimated’ to low nitrogen concentrations prior to exposure to intermittent PFD. The model was then forced with saturating nitrogen supply for the duration of exposure to intermittent PFD.

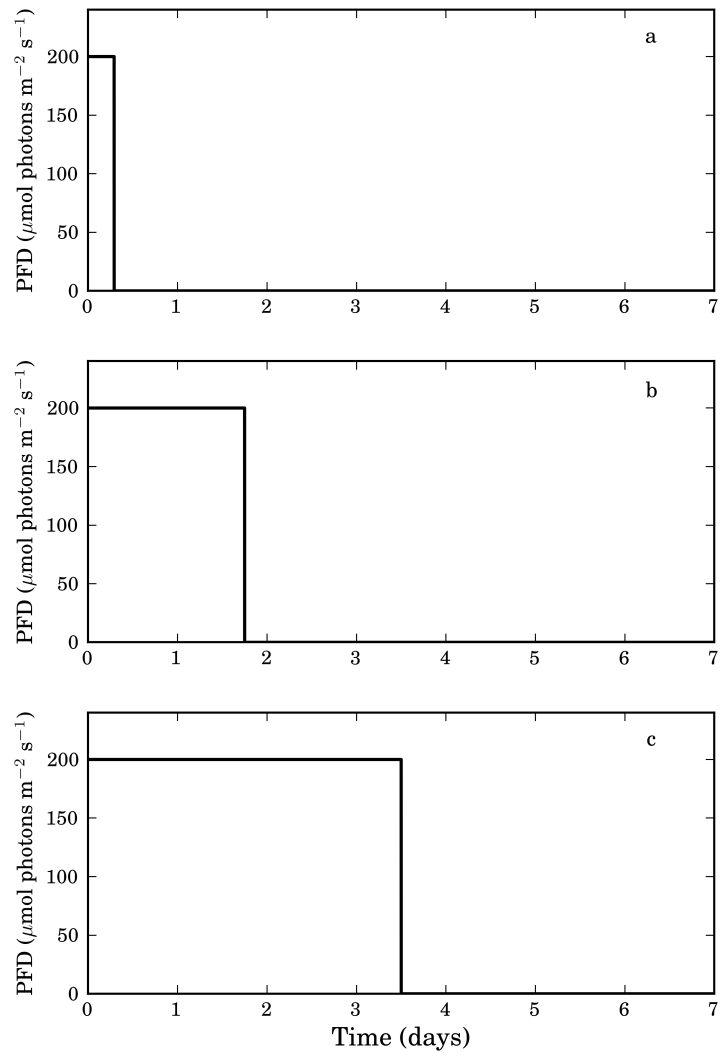


Figure 3: Graphical illustration of the second sensitivity case (equation 3), corresponding to  $\rho = 0.28$ ,  $\rho = 1.75$  and  $\rho = 3.5$  for panels (a), (b) and (c) respectively.

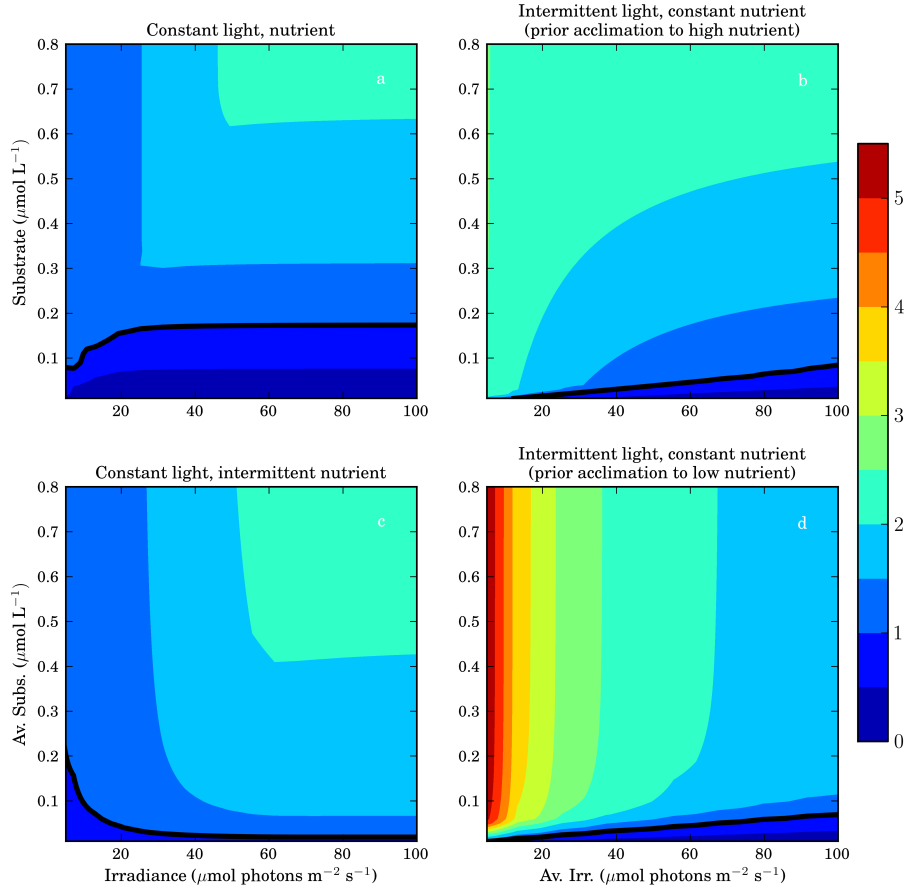


Figure 4: Sensitivity of the results presented in the main text to scenarios in which organisms experience relatively prolonged periods in and out of resource replete conditions (i.e. according to equation 3). Contours are the ratio of *S. costatum* to *P. marinus* (SS120) average daily growth rate in a range of PFD and nutrient conditions. Hot colored regions indicate *S. costatum* should have an advantage in terms of average daily growth rate. Cool colored regions corresponding to values less than unity indicate SS120 should grow faster. In each case the thick black line shows where both organisms have equal growth rates. a) constant light, constant nutrient conditions. b) Constant nutrient; PFD ‘switched’ according to equation 3. c) Constant PFD; nitrogen supply ‘switched’ between 1 and 0  $\mu\text{mol photons L}^{-1}$ , again according to equation 3. d) Same experiment as in panel (b), this time modeled organisms were ‘acclimated’ to low nitrogen concentrations prior to exposure to intermittent PFD. The model was then forced with saturating nitrogen supply for the duration of exposure to intermittent PFD.