Mathematical Model of the Size-Structured Growth of Microalgae Dividing by Multiple Fission

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Some microalgae strains divide by multiple fission, i.e. give rise to a number of daughter cells which might change at each cytokinetic cycle. In this work, a novel mathematical model to simulate the size-structured growth of microalgal strains dividing by multiple fission is proposed. Model results are validated by comparison with experimental data.

Introduction

Most models describing the structured growth of microalgae are based on the hypothesis that they divide by binary fission. However, several strains can generate more than two daughter cells according to a mechanism called multiple fission. This may affect productivity of microalgal cultures as well as the downstream treatments such as harvesting and lipid extraction. Therefore, a novel mathematical model to simulate the size-structured growth of microalgal strains dividing by multiple fission is proposed. Model results are validated by comparison with literature experimental data (Concas et al., 2016).

Conceptual model

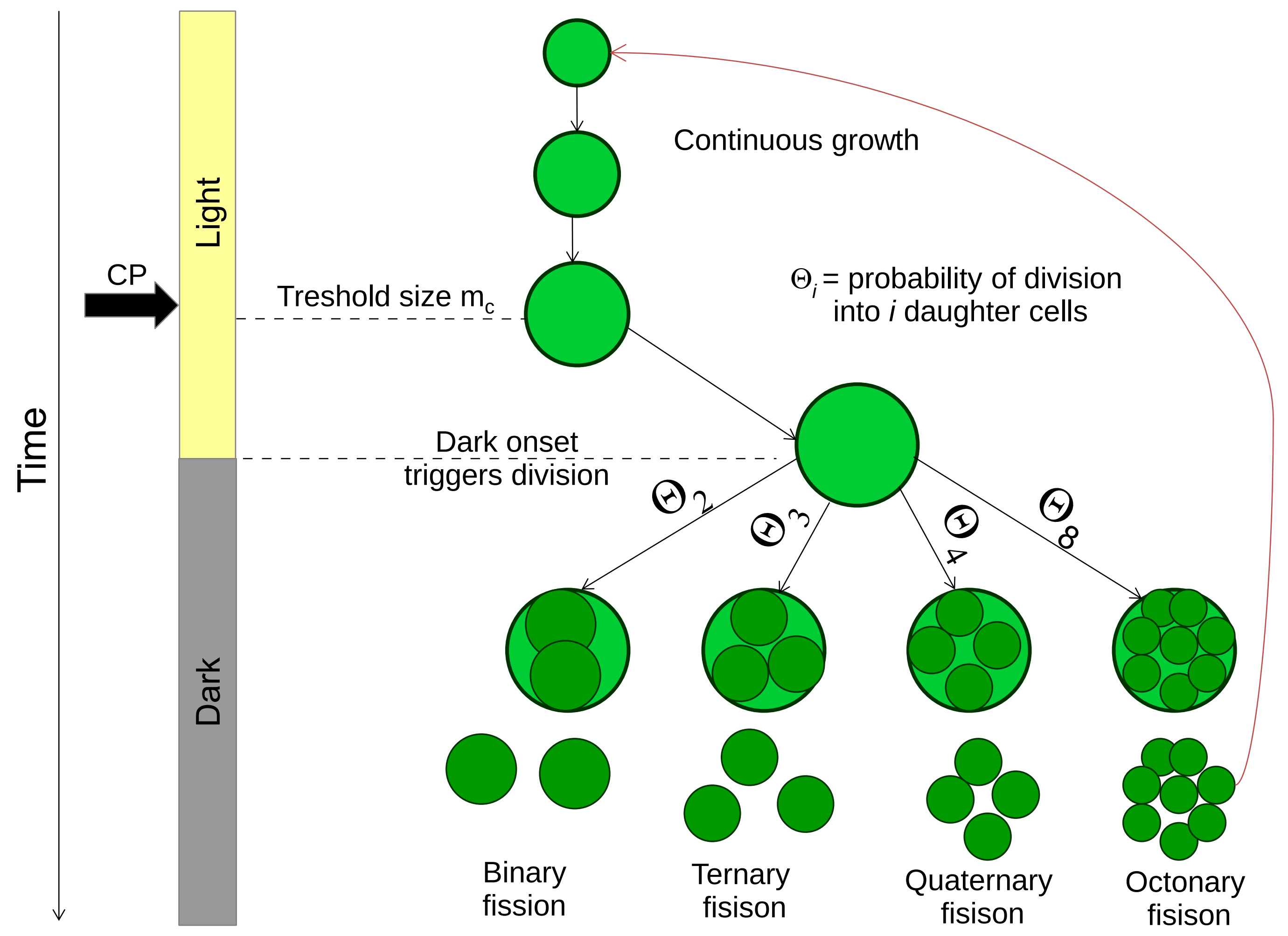

Figure 1. Scheme of the growth and division by multiple fission.

Microalgae cells grow in presence of light until they reach a critical mass/size. At this point cells are committed to divide. However, the division process is postponed so that to occur in the dark and avoid DNA photo-damage phenomena. During night, cells divide and the probability to give rise to a specific number of daughter cells can be experimentally evaluated.

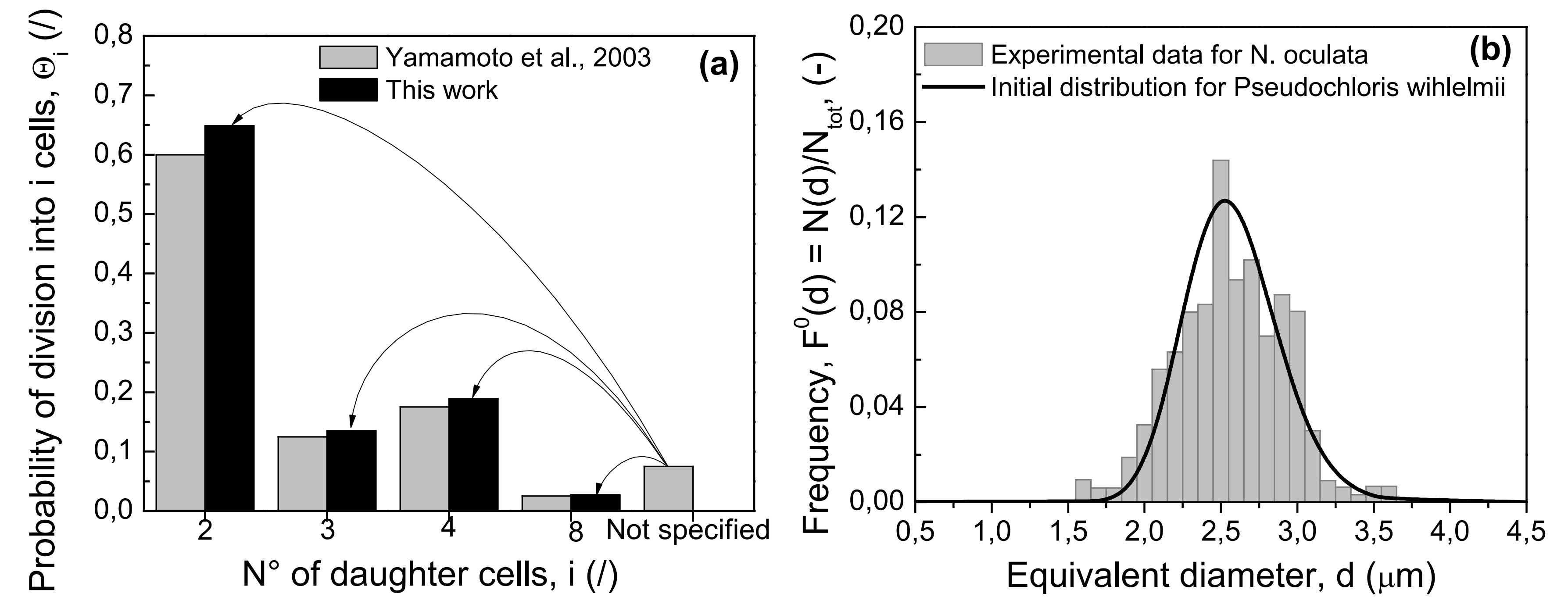

Figure 2. Probability of division into i daughters (a) and initial distribution (b).

Relevant model equations (Population Balance)

$$\nu_m = \frac{dm}{dt} = \left[\mu_{\max} \cdot g\left(I_{av}\right) \cdot \prod_{j=1}^{2} \frac{C_j}{K_j + C_j}\right] \cdot m^{2/3} - \mu_c \cdot m$$

$$D(m) = \mu_{\max} \cdot \prod_{j=1}^{2} \frac{C_j}{K_j + C_j} \cdot m^{2/3} \cdot \frac{f(m)}{1 - \int_0^m f(m')\,dm'} \cdot \left[1 - H\left(I_{av}\right)\right] \cdot \psi(m)$$

$$B(m) = \int_m^\infty \Gamma(m', C_j) \cdot \frac{1}{m'} \cdot \vartheta(m, m') \cdot \psi(m') \cdot dm'$$

$$\vartheta(m, m') = \sum_{i=2,3,4,8} m' \cdot i \cdot \Theta_i \cdot p_i(m, m') = \sum_{i=2,3,4,8} \frac{i \cdot \Theta_i}{\beta(\alpha_i, \delta_i)} \cdot \left(\frac{m}{m'}\right)^{\alpha_i} \left(1 - \frac{m}{m'}\right)^{\delta_i}$$

$$\frac{\partial \psi}{\partial t} + \frac{\partial(\nu_m \cdot \psi)}{\partial m} = -\Gamma(m, C_j) \cdot \psi + \sum_{i=2,3,4,8} i \cdot \Theta_i \cdot \int_m^\infty \Gamma(m', I, C_j) \cdot p_i(m, m') \cdot \psi(m') \cdot dm'$$

$$\frac{dC_j}{dt} = -\frac{1}{y_{X/j}} \int_0^\infty \nu_m\left(m, I, C_j\right) \cdot \psi(m) \cdot dm \quad \text{where} \quad j = 1,..2; \quad 1 = NO_3^-; \quad 2 = H_2PO_4^-$$

References

[1] Concas, A., Pisu, M., and Cao, G., 2016. Chem. Eng. J., 287, 252-268.

Results and discussion

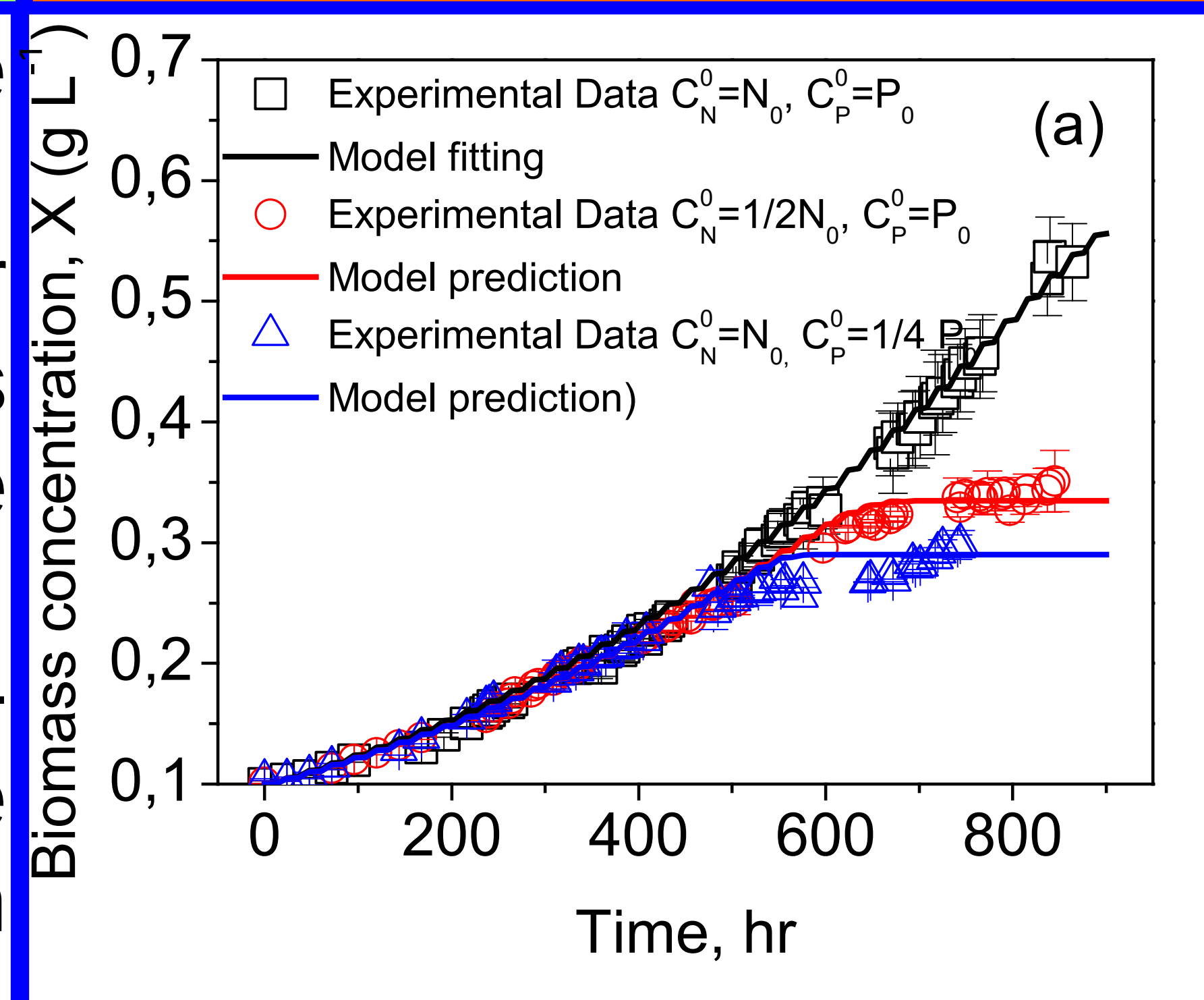

Figure 3. Comparison of model results and experimental data in terms of biomass concentration.

A good matching is obtained between model and experimental results. Model permits evaluating the size structure evolution of microalgal cells (cf. Fig. 4)

Model permits simulating the evolution of the size structure of microalgae population and the number of cells Vs time.

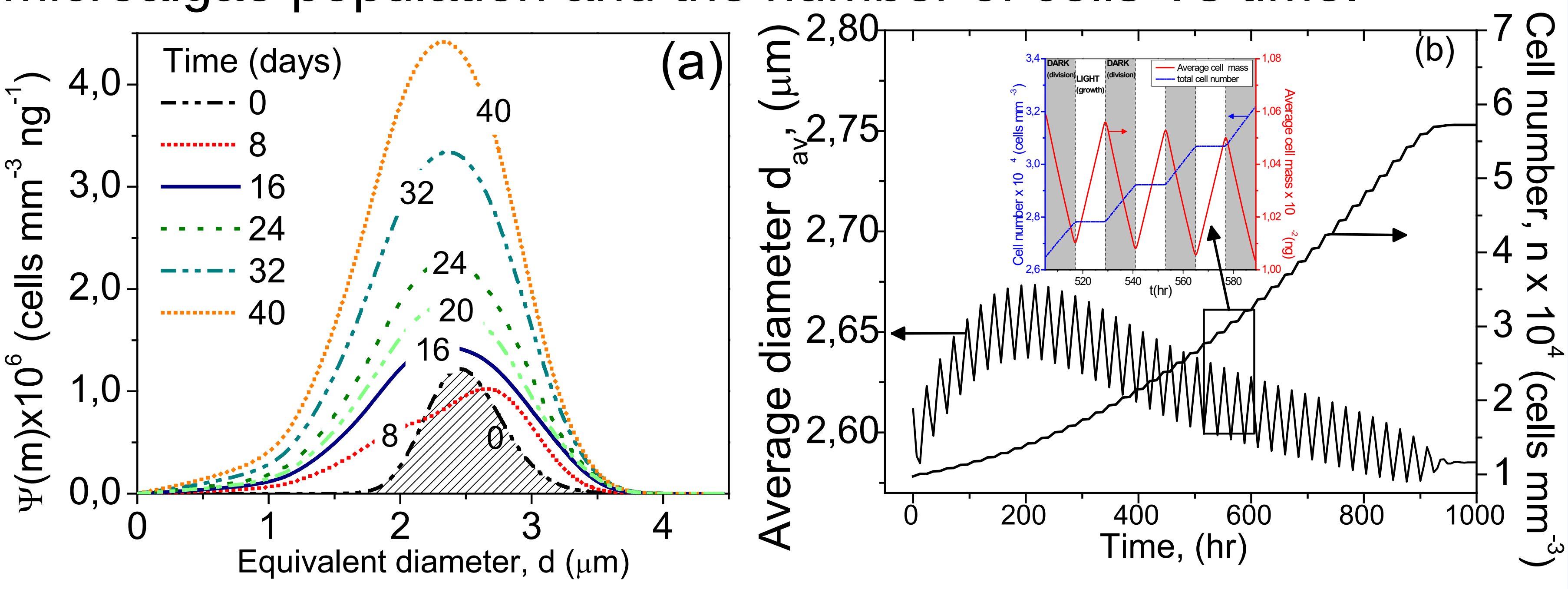

Figure 4. Simulated evolution of cell size distribution (a) and average diameter or total number of cells (b).

From model simulations it can be extrapolated that the difference in cell division mode affects the culture productivity and size structure evolution (Fig. 5 and Fig 6)

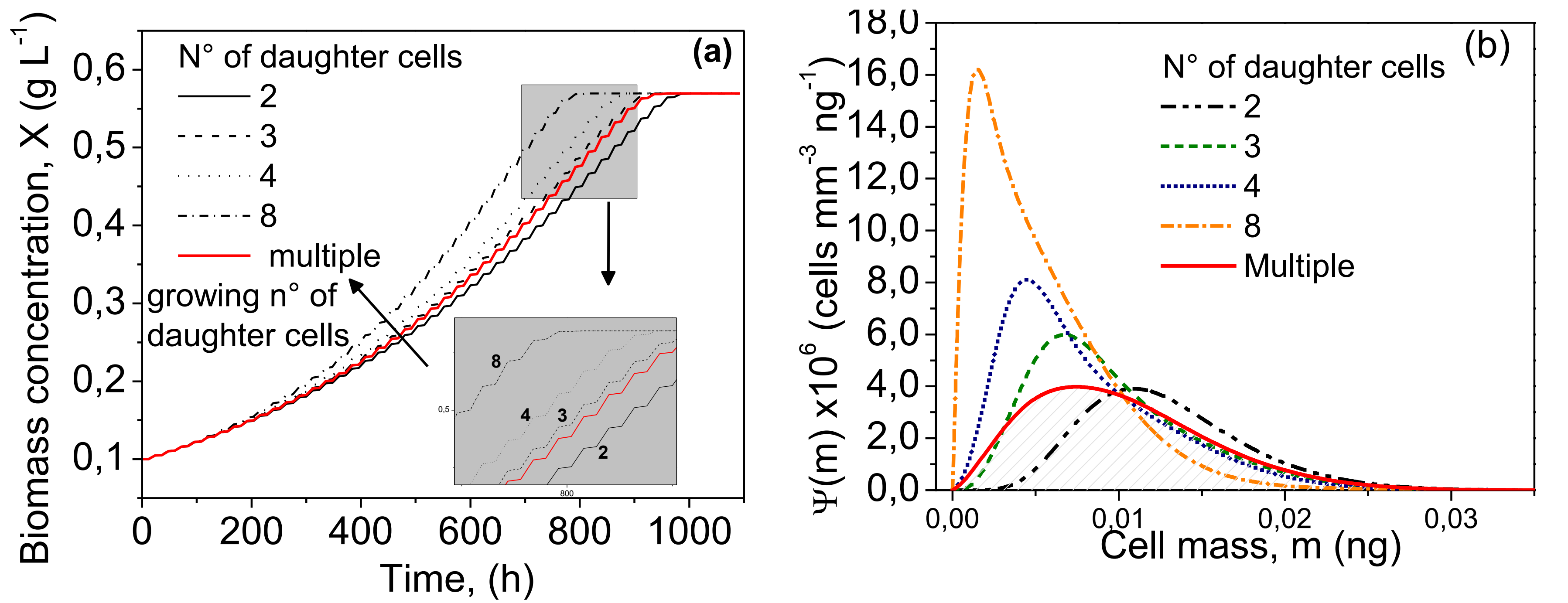

Figure 5. Simulated biomass evolution (a) and final distribution of cells (b) under different division conditions.

The model could be thus exploited to suitably design the cell size dependent processes of the microalgae based technology, for instance coagulation and flocculation for harvesting (Fig. 6).

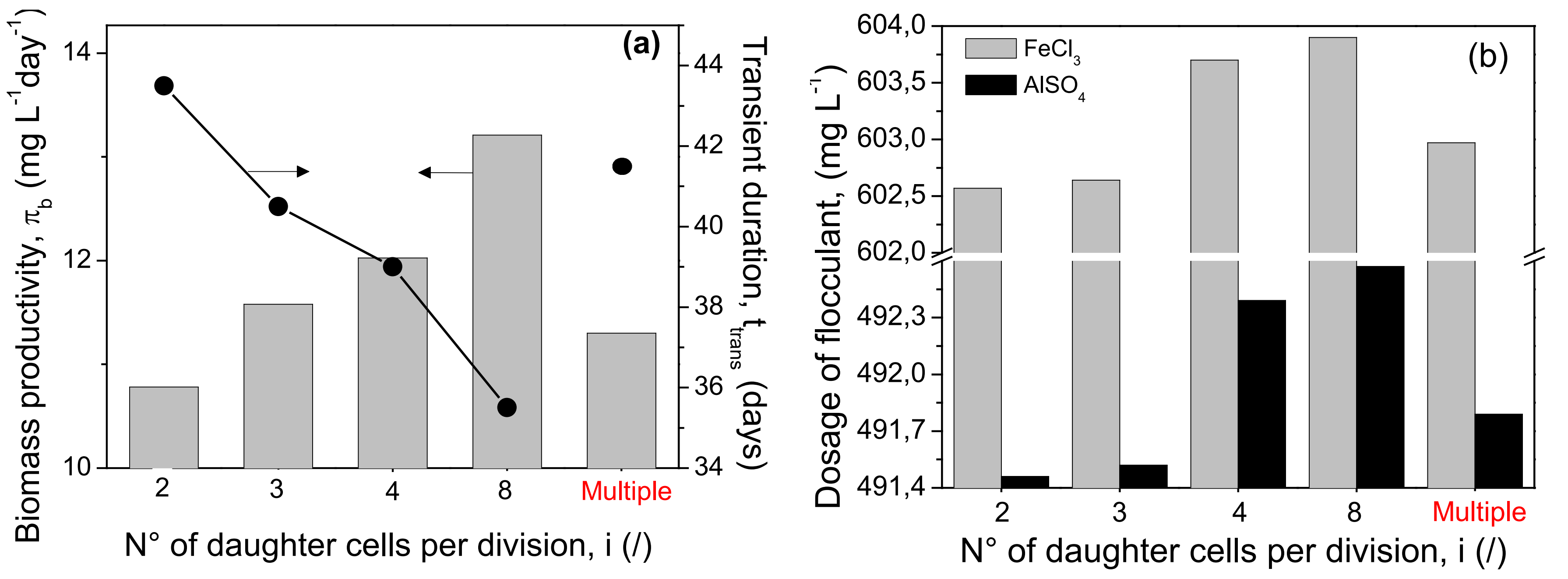

Figure 5. Effect of division mode on the biomass productivity (a) and dosage of flocculants (b)

Conclusions

The proposed model well simulates experimental data. The model, in addition to simulate the cell size structure evolution allows one to suitably evaluating industrially relevant parameters such as biomass productivity and flocculants dosage. This can result in the optimization of the design of systems operating with microalgae dividing by multiple fission

Acknowledgements

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