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MODELING OF ALGAL PERIPHYTON GROWTH RATE: Taking into account the feedback effects of biomass accumulation

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ABSTRAK

Konsep pertumbuhan perifiton secara umum dianggap sebagai unit fungsional, tanpa memperhitungkan dinamika berbagai komponen seperti yang telah banyak dilaporkan, dan menjadi acuan pada pemodelan pertumbuhan alga perifiton pada penelitian ini. Data eksperimental tentang pertumbuhan biomassa perifiton terhadap waktu telah digunakan untuk menguji dua hipotesis dasar dalam memperhitungkan efek umpan balik pada laju pertumbuhan perifiton. Kurva pemodelan dan data eksperimen menunjukkan bahwa biomassa tumbuh secara eksponensial antara hari ke 14 dan 28. Antara hari ke 21 dan 28, dua fungsi tingkat penurunan dan nilai koefisien {pengurangan laju pertumbuhan = f (biomassa)} memiliki peran yang lebih penting. Model ini memperhitungkan penurunan tingkat pertumbuhan oleh proses drop-out *dan efek retroaktif biomassa. Bagaimanapun, ini menunjukkan point besar kemajuan untuk mencapai ekspresi matematis yang dapat diandalkan dan mampu secara efektif menyingkat aksi variabel abiotik dan interaksi antara unit yang kompleks dan berubah-ubah.*

Kata kunci : Alga perifiton, laju pertumbuhan, pemodelan, pertumbuhan biomassa, biomassa *drop-out*

ABSTRACT

The concept of periphyton growth is globally regarded as a functional unit, without considering the dynamics of various components as have been reported by earlier scholars, and is used as references to the algal periphyton growth modeling conducted in this study. Experimental data on the growth of periphyton biomass versus time was used to test two basic hypotheses to account for feedback effects on periphyton growth. Modeling curves and experimental data showed that biomass grew exponentially between 14 and 28 days. Between 21and 28 days, the two functions of reduction rate and coefficient value {reduction of the growth rate = f (biomass)} has a more important role. This model takes into account the decline in the growth rate of drop-out processes and biomass retroactive effect. However, it shows great point of progress to achieve a mathematical expression that is reliable and able to effectively shorten the actions of abiotic variables and interactions among complex and ever changing units.

Keywords: Algal-periphyton, growth rate, modeling, biomass growth, drop-out biomass

INTRODUCTION

Today, modeling is rarely used to study the dynamics and processes involved in the periphyton community compared to the phytoplankton community itself. Researchers had previously done some modeling studies on periphyton starting from a simple to a more complex empirical model associated with one process or community dynamics and considering one or more factors, as such have been reported by Mcintire (1973), Horneretal (1983), Stevenson (1986), Biggs (1988), Momo (1995), Wanner & Reichert (1996), Saravia *et al*. (1998), Asaeda & Son (2001).

McIntire (1973) has developed two models of algal periphyton growth, which simply used a biomass variable and four processes (primary production, respiration, two types of export function), three variables and eight processes including allochthonous and predation or grazing by herbivores). This modeling is based on the results of a seven-year study on the growth of periphyton communities conducted in artificial canals with a population composed of diatoms, cyanobacteria, chlorophytes, filamentous algae (Chrysophyceae) and heterotrophic microorganisms including insect larvae (McIntire, 1968a,b). In most experiments larger herbivores like snails are not included. This is aimed to analyze the response of algal periphyton to the changes in physical variables. Simulation model developed by McIntire (1973) was based on the assumption that the growth of periphyton can be considered as a single unit regardless the population quantitative dynamics which have more constituents. In this case, the periphyton growth concept is globally regarded as a single functional unit without considering the dynamics of various components, as it has been reported by McIntire (1968a). In this study this concept is used as reference to periphyton growth modeling.

Table 1. Shows some examples of mathematical models that have been used to describe the various processes associated with the development and dynamics of periphyton.

Year	Authors	Type	Variables	Processes
1973	McIntire	simple	biomass	P-I, Respiration, export
1973	McIntire	complex	biomass	P-I, Respiration, exportation, grazing, nutrient
1995	DeAngelis *et al.*	empirical	biomass	nutrient & storage zone
1995	Marna	logistics	biomass	current
1996	Uehlinger *et al.*	empirical	biomass	detachment, discharge
1998	Saravia *et al.*	complex	biomass	current, nutrient, reproduction
1998	Biggs *et al.*	matrices	growth, biomass	flow, nutrient, grazing
1999	Biggs	statistical	Chl.*a*	flow, nutrient
1999	Morin *et al.*	empirical	chl.*a*, temperature	GPP(gross primary production)
2001	Asaeda & Son	empirical	biomass,	flow, nutrient
2004	Flipo *et al.*	complex	biomass	flow, nutrient

METHODS

Periphyton growth data used in the model are obtained from the results of experiments that have been conducted in the Sevab laboratory, University of Paul Sabatier, Toulouse, France. The current study, the experimental data on the growth of periphyton biomass versus time have been used to test two basic hypotheses in calculating the feedback effects on periphyton growth. In this study, the growth at time t is the sole dependence on the environmental condition (light, temperature and nutrient levels are unlimiting) and the biomass at t-1.

The feedback effect can occur due to the release or flushing of biomass. It takes place directly on the rate of growth (biomass accumulation) that gives a direct effect on the bioderm metabolism efficiency resulting in the decrease of growth rate. Two hypotheses have been tested. They are a). drop-out rate is proportional to the growth of periphyton biomass, b). drop-out rate is proportional to the increase of biomass that adds the threshold effect controlled by the biomass itself.

In both cases, the maximum growth rate is calculated from the equations and parameter values that are deducted from laboratory experiments. This calculates the biomass growth rate based on the values of the environmental parameters (temperature, light), as has also been done by Muller-Feugamodels (1999) and Lehman *et al.* (1975). Thus, in a certain environment algal growth rate is fixed and does not change from time to time. However, if we consider the experimental values, the maximum growth rate (μmax) is only valid for a very short period of time that is the exponential growth phase (which is also in accordance with the definition of μmax), and does not apply to lag phase or aging phase. Therefore, it is necessary to find a more complex formulation that can determine algal periphyton growth at all times.

Mathematical equations offer broad ranges that may provide solutions to the growth model. There are many studies have been tested to calculate the effect of biomass growth rate, but the simple solution with biological significance (simplicity and clear parameters) was selected and described below.

RESULT AND DISCUSSION

Hypothesis1. Decrease of growth by the drop-out value of biomass.

The growth rate at time t is considered as a result of the maximum growth rate [μmax=f(I, T)] multiplied by the coefficient of the biomass drop-out value (Td) which is a function of the biomass at t-1, according to the exponential equation below:

$Td = Td_{min} * EXP(K_{der} * Biomass)$,

where:

Td = % of biomass drop-out

K_{der}= constant

$Biomass_t = Biomass_{t-1} * exp(\mu max) - Td$

Figures 1a and 1b illustrate the suitable effect of the equation.

Hypothesis 2. Growth will decline mainly due to the drop-out rate of the biomass by considering the retroactive effect of the growth rate.

a). The growth rate at time t is considered as a result of the maximum growth rate [μmax=f(I, T)] multiplied by the coefficient of the biomass drop-out value (Td) which is a function of the biomass at t-1, with an exponential equation.

$Td = Td_{min} * EXP(K_{der} * Biomass)$,

where:

Td=Percentage of the biomass drop-out value

b). Biomass has dual effects on the growth rate of periphyton, i.e. reduction of the growth rate below the minimum value (Binf) and reduction of the growth rate above the optimum value (Bopt), by taking into account the higher biomass values (Bsup).

The reduction rate (TB) is related to the growth rate of biomass [µmax=f(I, T)] and yields to the following equation:

$T_B = C_t * C_A^2/C_B^2$

where: Ct= constant (amplitude ratio), C_A=B–Bopt,

$C_B = B_{Sup} - B_{opt}$ if $B>B_{opt}$ and $B_{opt} - B_{inf}$ if $B<B_{opt}$

B: biomass - t^{-1},B_{Sup}, B_{opt} and B_{inf} are defined as the threshold values of periphyton biomass.

This equation is able to describe:

1. Lag phase or slowed in accordance with the critical growth of biomass on the substrate. Only the first biomass of periphyton that attach will grow well and fast during the exponential phase.
2. Aging phase in which usually occurs two phenomena: first, the occurrence of the drop-out due to the excessive accumulation of biomass. Second, the decline in the growth rate due to the thickness of the substrate that inhibits the metabolisms, such as light penetration for photosynthesis.

Figure 3 shows the evolution of the various theories on the decline in the growth rate of periphyton communities during simulations.

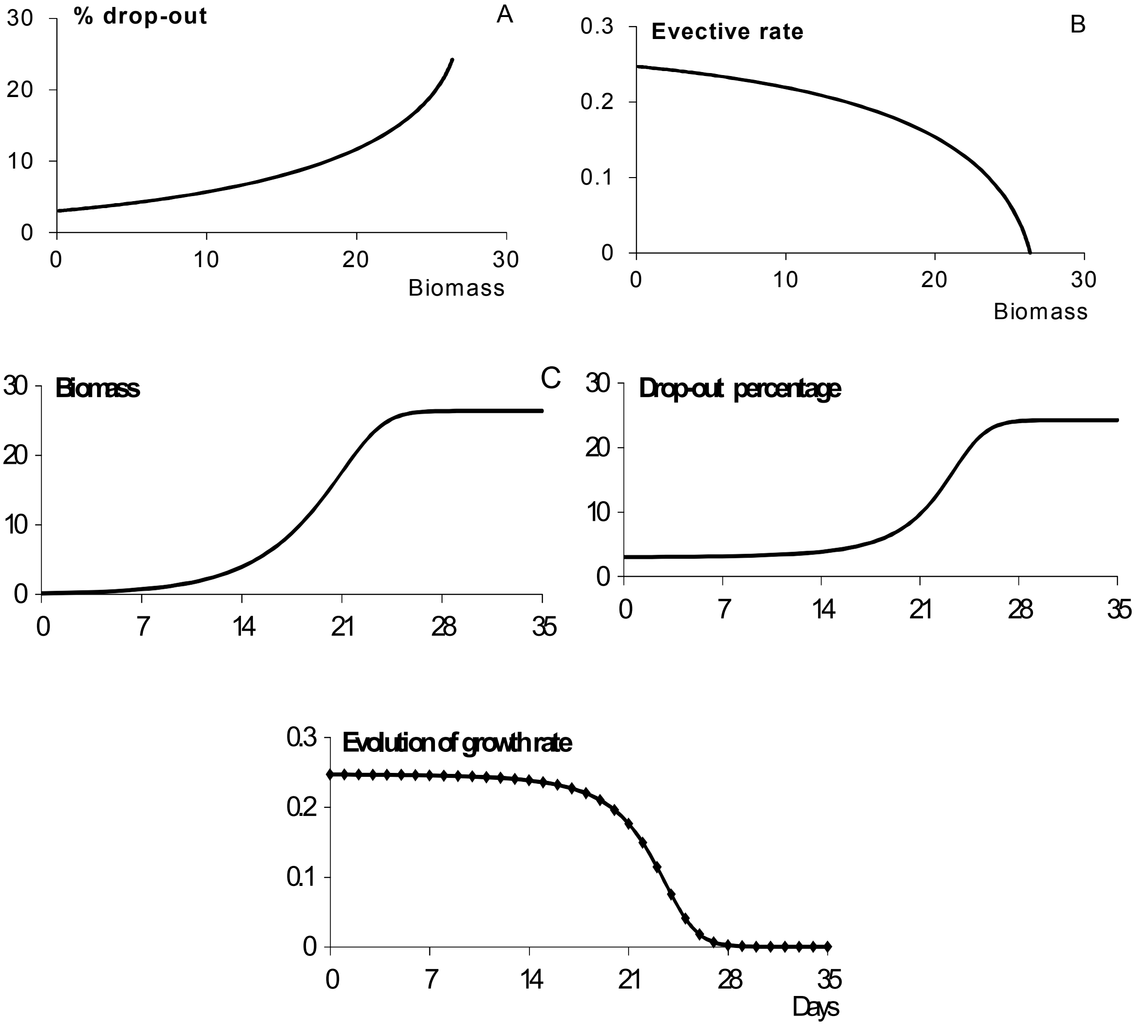

Figure 1. (a) Effect of biomass on the drop-out rate (Td = 3, Kd=0.06). (b) Effect of biomass on the actual growth rate (µmax= 0.28, Td= 3, Kd=0.06). (c) Simulation graph of different variables for the initial biomass with dry weight of 0.1 mgm^{-2} and parameters as follows: (µmax = 0.28, Td= 3, Kd=0.06).

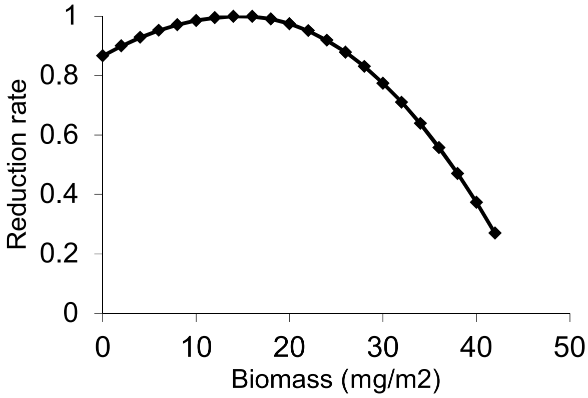

Figure2. Effects of biomass growth rate reduction (Binf = 1, Bopt = 15, Bsup = 30).

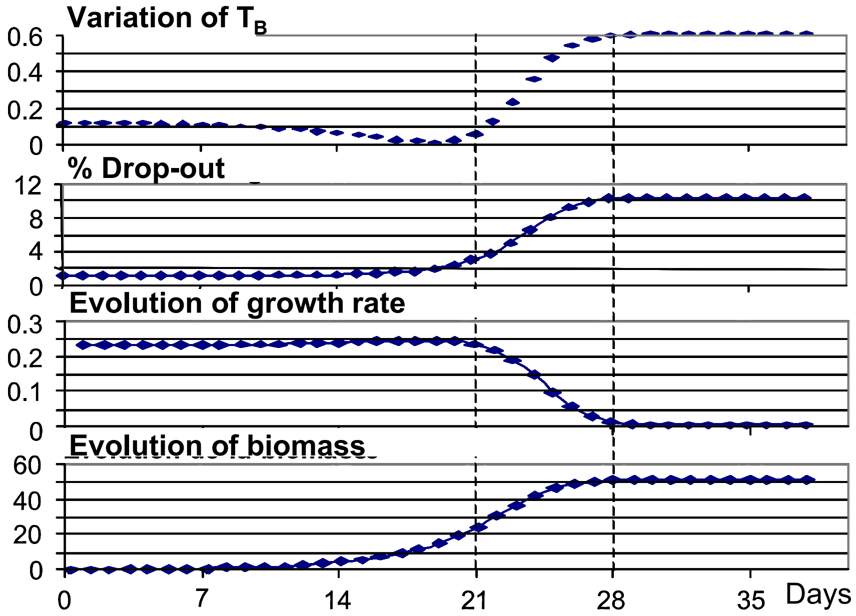

Figure 3. Simulation of biomass accumulation over time (initial biomass = 0.15, μmax = 0.26 d^{-1}) which derived from a combination of functions that link the function of the growth of the biomass threshold TB (Binf = 1, Bopt = 15, Bsup = 30, Ct = 0.1) and the drop-out rate (Td = 1, Kd = 0.04).

Algae periphyton were cultured at laboratory scale. The culture model takes into account both the decrease of growth rate by drop-out factor and the retroactive effect from biomass (hypothesis 2). It is based on the data obtained in the experiments to determine the growth rate.

Modeling that only uses the drop-out values to describe the decline in the growth rate of periphyton biomass will show a very unsatisfactory result. However, parameter adjustment is necessary to obtain the clearer model. Table 1 showed that the model parameters have been adjusted on a case by case basis. Nevertheless, the changes in parameters are relatively low for other cases. Therefore, it is considered as perfect and satisfying relationships as demonstrated by the ratio between the direct measure of biomass values and the predicted values (Figure 5). In addition, the equations in the model tend to be consistent with the hypothesis 2.

Theoretical curve (Figure 3, example of the evolution of simulated biomass) and the experimental data show that biomass grows exponentially between days 14 and 28. Whereas, between days 21 and 28, the two functions of TB and Td {reduction of the growth rate = f(biomass)} has a more important role. This model takes into account the decline in the growth rate of drop-out process and the retroactive effect of biomass (hypothesis 2), used by the data obtained from the experiments to determine the growth rate (Figure 4.) Satisfactory results have been obtained during simulations (Figure 5.).

If temperature also plays a role in determining the growth rate of periphyton, then it can also affect the drop-out and biomass threshold. This means that the hypothesis can be accepted. It should be noted that the drop-out phenomenon of biomass can be influenced by the amount and composition of extra cellular polymeric substances (EPS) found in periphyton biofilms. Applegate and Bryers (1991) stated that enzymatic production processes dependant on the changes in temperature and observed that at the lower level (20-40%) in the periphyton biofilm detachment is limited by the oxygen availability (a comparative

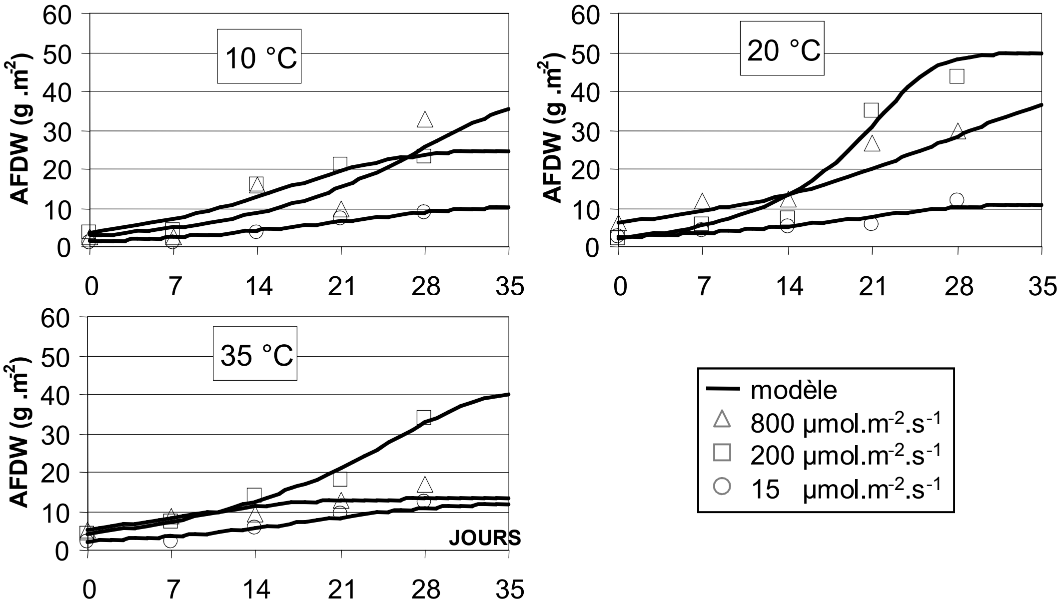

Figure 4. Test model (curves) and the observations.

Table 2. Adjustment of model parameters for various experiments.

Temperature	I =µmol/m2/s	Bo	µMAX	Taux Decr = A	Kder = N	D	Bio-Inf	Bio-Opt	Bio-Sup
10 °C	**15**	1	0,1	1,1	0,2	0,0	1	10	20
	300	4	0,1	1,5	0,1	0,0	1	20	25
	800	3	0,1	1,2	0,0	0,0	1	15	20
20 °C	**15**	2	0,1	0,8	0,2	0,5	1	10	15
	300	2	0,2	1,0	0,0	0,1	1	30	40
	800	6	0,1	2,0	0,0	0,3	1	20	40
35 °C	**15**	2	0,1	1,2	0,2	0,1	1	10	20
	300	4	0,1	1,2	0,0	0,1	1	20	30
	800	5	0,1	1,0	0,2	0,4	1	10	20

study with carbon constraints). This is because high concentrations of EPS fractions and calcium (EPS is controlled by the production and extracellular enzymatic degradation). Robinson *et al*. (1984) and Characklis (1990) describe a direct relationship between the level of EPS production and the specific growth rate of cells.

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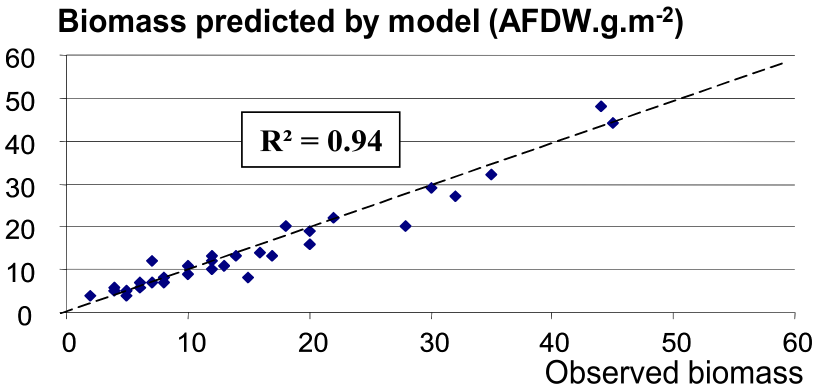

Figure 5. The relationship between observed and predicted values.

Flushing or drop-out of biomass could happen because the biomass auto-accumulates independently, but it is also intervened by abrasion events related to physical changes caused by current flow. Flood (MES) cause an increase in water flow velocity (Steinman and McIntire, 1986, Biggs & Murray, 1989, McCormick & Stevenson, 1991, Ghosh and Gaur, 1998). However, all benthic community does not respond in the same way, as well as filamentous algae that thrive in slow streams with sufficient light penetration (Hill, 1996). Modeling shows that the growth rate of periphyton cannot be expressed in simple ways, or if it only refers to the two parameters (light and temperature). It shows great progress points to achieve mathematical expression that is reliable and effectively shorten the action of abiotic variables and interactions among complex and changing units.

REFERENCES

Applegate, D.H. & Bryers, J.D., 1991 Effects of Carbon and Oxygen Limitations and Calcium Concentrations on Biofilm Removal Processes, Biotech.Bioeng. Vol.37, (1), pp. 17-25

Asaeda, T, Son, D. H., 2000. A Model of the Development of a Periphyton Community: Resource and Flow Dynamics. *Ecol. Modelling* 137: 61–75.

Characklis, W.G., 1990 Kinetics of Microbial Transformations, in: *Biofilms* (ed.: Charaklis and Marshall), John Wiley & Sons, New York, 1990

Ghosh, M., & J. P. Gaur. 1998. Current Velocity and the Establishment of Stream Algal Periphyton Communities. *Aquatic Botany* 60:1-10.

Hamilton, D.P., & Schladow, S.G., 1997. Prediction of Water Quality in Lakes and Reservoirs. Part I — Model description. *Ecol. Modelling* 96:91–110.

Haney, J.D., & Jackson, G.A., 1996. Modeling Phytoplankton Growth Rates.*J. Plankton Res.* 18: 63–85.

Homer, R. R., E. B. Welch, & R. B. Veenstra, 1983. Development of Nuisance Periphytic Algae in Laboratory Streams in Relation to Enrichment and Eelocity. ln R. G. Wetzel (ed.), Periphyton of Freshwater Ecosystems. Dr W. Junk Publishers, The Hague: 121-134.

Kondo, J., & Watanabe, T., 1992. Studies on the Bulk Transfer Coefficients Over a Vegetated Surface with a Multilayer Energy Budget Model. *J. Atm. Sci.* 49:2183–2199.

Lehman , J.T., D.B. Botkin and Likens, G.E., 1975. The Assumptions and Rationales of a Computer Model of Phytoplankton Population Dynamics. *Limnol.Oceanogr.*20 (3): 343-364

McCormick, P. V., & Stevenson, R. J., 1991. Grazer Control of Nutrient Availability in the Periphyton. *Oecologia* 86:287-291.

Mclntire, C. D., 1966. Some Factors Affecting Respiration of Periphyton Communities in Lotic Environments. *Ecology* 47: 918-930.

Mclntire, C. D., 1968a. Physiological-Ecological Studies of Benthic Algae in Laboratory Streams. *J. Water Pollut. Control Fed.* 40: 1940-1952.

Mclntire, C. D., 1968b. Structural Characteristics of Benthic Algal Communities in Laboratory Sreams.*Ecology* 49: 520-537.

Mclntire, C. D., 1973. Periphyton Dynamic in Laboratory Stream: a Simulation Model and its Implications. *Ecol. Monogr.* 43:399-420.

Mclntire, C. D., & H. K. Phinney. 1965. Laboratory Studies of Periphyton Production and Community Metabolism in Lotic Environments. *Ecol. Monogr.* 35: 237-258.

Momo, F.R., 1995. A New Model for Periphyton Growth in Running Waters. *Hydrobiologia* 299:215–218.

Mulholland, P.J., Steinman, A.D., Marzolf, E.R., Hart, D.R., & DeAngelis, D.L., 1994. Effect of Periphyton Biomass on Hydraulic Characteristics and Nutrient Cycling in Streams. *Oecologia* 89:40–47.

Muller-Feuga, A., 1999. Growth as a Function of Rationing: a Model Applicable to Fish and Micro-algae. J. *Exp. Mar. Biol. and Ecol.*, 236 : 1-13.

Robinson, J.A., Trulear, M.G. & Characklis, W.G., 1984. Cellular Reproduction and Extracellular Polymer Formation by Pseudomonas Aeruginosa in Continuous Culture. Biotech. Bioeng., Vol. 26, pp. 1409-1417.

Saravia, L. A., Momo, F., & Boffi Lissin, L. D., 1998. Modeling Periphyton Dynamics in Running Water. *Ecological Modeling* 114 35–47.

Steinman, A. D., & McIntire, C. D., 1986. Effects of Current Velocity and Light Energy on the Structure of Periphyton Assemblages in Laboratory Streams. J. *Phycol.* 22:352-361.

Stevenson, R.J., 1986. Mathematical Modeling of Epilithic Diatom Accumulation. In: Ricard, M. (Ed.), Proceedings of the Eighth Diatom Symposium. Koeltz Scientific Books, Koenigstein, pp. 323-335.