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NET PRODUCTION MODELING OF PHYTOBENTHOS: INTEGRATION ON A SECTION OF GARONNE RIVER ACCORDING TO THE SEASON

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ABSTRACT

The analysis of daily curves of dissolved oxygen in the Garonne, downstream of Toulouse, shows that the river is generally heterotrophic. It appears in contradiction with the fact that the river bed is covered with a thick periphytic biofilm. From the data obtained in-vitro and in-situ, we developed a model to calculate the net production, integrated over the section. This model makes it possible to simulate various environmental situations: variations of the wet cross section, seasons and turbidity. The simulations show that some zones of the section are highly productive. For the majority of the cases, the daily balance photosynthesis/respiration remains less than one. This negative daily balance is equilibrated by the re-aeration rate associated with the turbulent flow of the Garonne. This work shows, however, that the oxygen level in the river is strongly dependent on the total rate of respiration, so that a weak increase (pollution for example) could quickly induce a reduction in the dissolved oxygen.
Key words: Modelling, periphytic biofilm, net production, oxygen balance, river.

ABSTRAK

Analisis kurva harian oksigen terlarut di Garonne, di daerah hilir kota Toulouse Perancis, menunjukkan bahwa perairan ini umumnya tergolong heterotrofik. Hal ini kelihatannya menimbulkan kondisi yang cenderung kontradiksi dengan fakta bahwa kenyataannya dasar sungai ditutupi dengan perifiton yang tebal. Dari data yang diperoleh secara in-vitro dan in-situ, kami mengembangkan sebuah model untuk menghitung produksi bersih, yang terintegrasi di setiap bagian sungai. Model ini memungkinkan untuk mensimulasikan situasi berbagai kondisi lingkungan: variasi penampang sungai, musim, dan kekeruhan. Hasil simulasi menunjukkan bahwa beberapa zona bagian tersebut sangat produktif. Untuk sebagian besar kasus, kesetimbangan harian fotosintesis / respirasi masih tetap kurang dari satu. Kesetimbangan harian negatif ini diequilibrasi oleh proses re-aerasi oleh aliran turbulen yang terjadi dalam sungai Garonne. Bagaimanapun penelitian ini menunjukkan bahwa tingkat oksigen di sungai sangat tergantung pada laju respirasi total, sehingga peningkatan yang lemah (polusi misalnya) dengan cepat dapat menyebabkan penurunan oksigen terlarut.
Kata kunci: Pemodelan, bio-film perifiton, produksi bersih, keseimbangan oksigen, perairan sungai.

INTRODUCTION

As the fourth largest river in France, the Garonne is about 525 km in length with a total catchments area of 57 000 km^2 and a specific flow of 11.4 L s^{-1} km^{-2} (Reyjol 2001). The Garonne crosses the city of Toulouse to join the Dordogne River in Bordeaux (Fig. 1). This river undergoes a degradation of water quality downstream of Toulouse (more than 740,000 inhabitants) (Amigues *et al.* 2002). In the area of Toulouse, the river remains shallow (about 1 meter) with a wide bed (100 m) and a mean velocity of 0.5 $m.s^{-1}$ (during summer). There is a low chlorophyll-*a* explained by a low residence time that does not permit the development of a limnetic phytoplankton (Dauta, 1978; Eulin, 1997 ; Améziane *et al.* 2003). The current evidence suggests that potamoplankton is limited by physical factors (Ameziane *et al.* 2003) whereas the periphyton is a significant primary producer, with an average biomass of 80 g dry weight. m^{-2} (Ameziane *et al.* 2001).

The irregular patterns of algal distribution on the river bed cross-sections, documented by several authors e.g. Cazaubon *et al*. 1995, Rolland *et al*. 1997, Smolar *et al*. 1998, have been also found (Fig. 2) in the Garonne (Ameziane *et al*. 2002, an, Garabetian *et al*. 2002). Therefore, photosynthetic and respiratory activities of algal communities change from shallower to deeper zones in response to environmental variables especially the light intensity (Hill, 1996; DeNicola, 1996). Considering a river cross-section, it is very difficult to assess a daily pattern of primary production and a P/R balance, for a given day, or to extrapolate this kind of results from various environmental conditions.

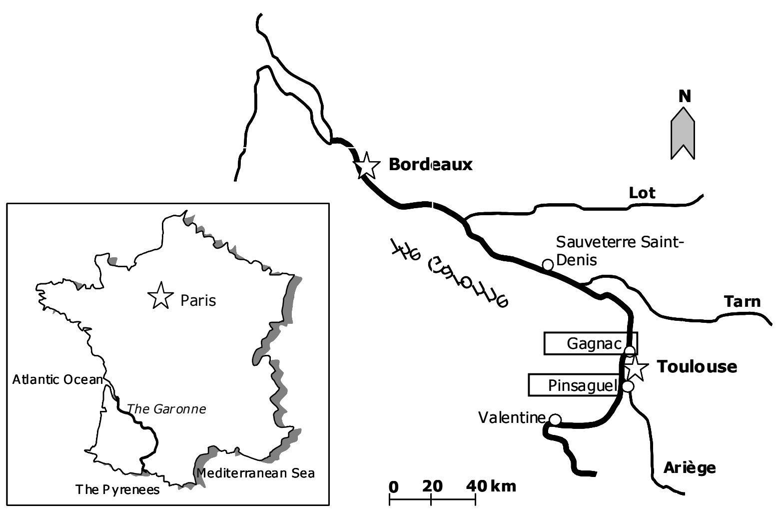

Figure 1. Garonne river : situation of Gagnac and Pinsaguel sites. However, this high primary productivity related to epilithic biofilm is in contradiction with the results obtained by Mathey (2000) from the analysis of continuous recordings of dissolved oxygen over a year : heterotrophy was the more frequent status.

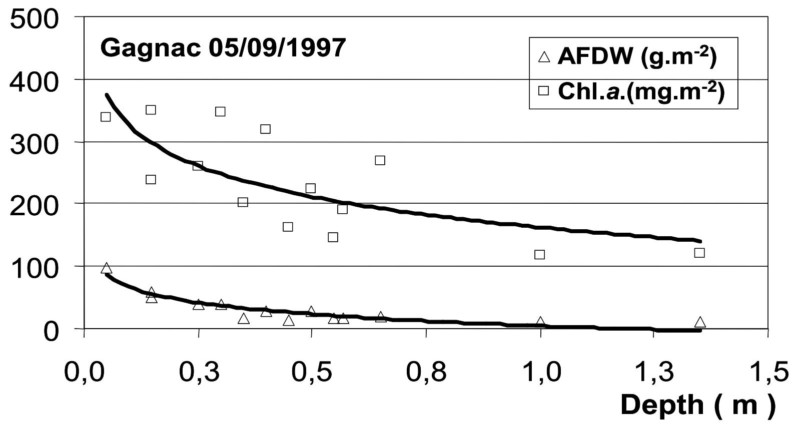

Figure 2. Distribution of periphyton biomass on a transversal section of Garonne (Gagnac). To obtain such estimations in the way to explain the conclusions of Mattey (2000), we used field data (Ameziane *et al*. 2002, Garabetian *et al*. 2002), *in-vitro* and *in-situ* experiments and a model developed to calculate gross and net production of periphyton (P3B : Primary Production of Phyto-Benthos).

MATERIALS AND METHODS

Photosynthesis and Respiration rates : we used the parameters KI, Pmax and Respiration rates estimated from laboratory measurements. Photosynthesis measurement has been conducted using a rectangular chamber (fig. 1) of plexi-glass having length = 25 cm, width = 18 cm and height = 7 cm. This device was first described by Duff *et al.* (1984), modified by Benmoussa (1995) and was improved for this study. The volume of the incubation chamber is approximately 0.8 liter that is enclosed in a box connected with a cryostat to maintain a constant water temperature. A magnetic stirrer was used to ensure a water circulation at the surface of the mat sample (about 75 rpm). The chamber was installed under a lighting system, using a halogen lamp Phyto Claude (400 watt). The morphological data and the biomass distribution (fig.2) refer to studies performed by Ameziane *et al.* 2002, Ameziane *et al.* (2003).

Every week, from 7 to 35 day old culture, the oxygen evolution was measured under five light intensities (30, 100, 300, 600 and 900 $\mu mol.m^{-2}.s^{-1}$). Dissolved oxygen was measured using an oxygen electrode YSI 5300 model inserted in the chamber.

The tile was immersed in the chamber which was filled up with water avoiding gas bubbles and closed : the photosynthesis and respiration measurements were carried out immediately. The oxygen slope was measured within a 15 minutes interval and increasing light intensities.

The oxygen quantity consumed or produced by the periphytic algal sample was calculated using the relation:

$$Y\ (mg\ O_2.m^{-1}\ h^{-1}) = [\{(X^*\ (O_2)t\ *\ V)100^{-1}\}]\ (T)^{-1}(A)^{-1}$$

Where:

X = Oxygen variation in % during incubation period
$(O_2)t$= Dissolved oxygen value in water related to temperature function ($mg\ l^{-1}$)
V = Volume of incubation chamber (L)
T = Incubation time (h)
A = Substrate surface (m^2)

Estimation of production by P3B model

The production modelling was estimated using "P3B model". The model was used with the morphological (environmental definition) and biomass data (definition of phytobenthos) of two sites (Gagnac and Pinsaguel) of the Garonne, near Toulouse. Light irradiance and photoperiod values were calculated for the latitude and a given Julian day by the P3B model, which allows also to simulate cloudy conditions.

RESULTS

Figures 3 and 4 present the calculations of gross and net production for the cross-sections of Gagnac and Pinsaguel, measured in July and December, during sunny and cloudy conditions. Generally, the production pattern was well correlated with the depths of the cross-section : the gross production rate is higher in the shallower parts while weaker in the deeper ones. The production rates were significantly different between July and December and also between sunny and cloudy conditions.

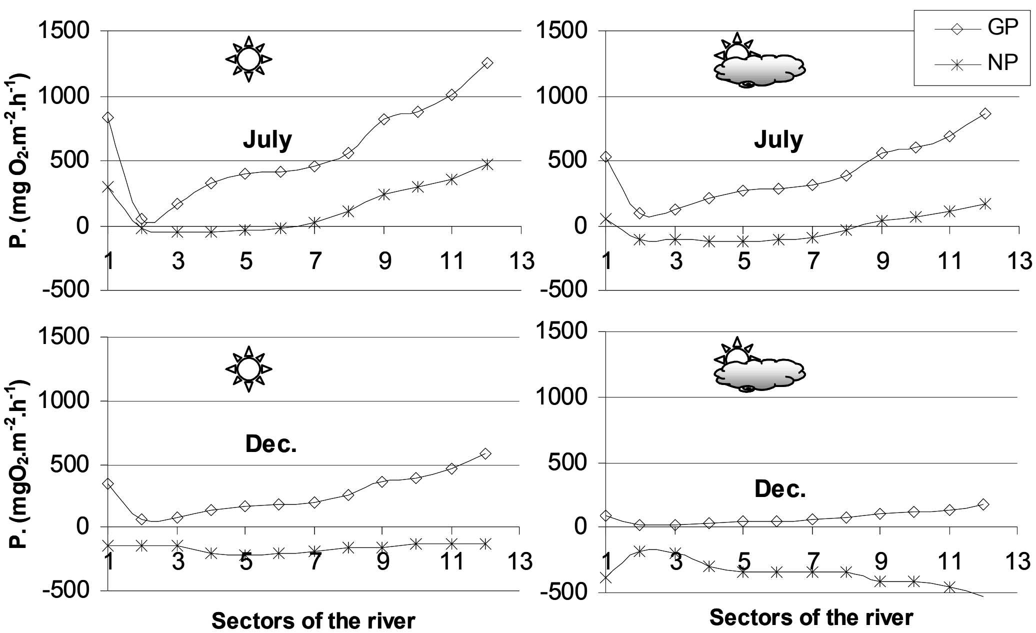

Figure 3. Gagnac site : Gross (GP) and Net (NP) production pattern. The cross-section of the river is represented by 12 sectors (8m each) representing a river of 96 meter width.

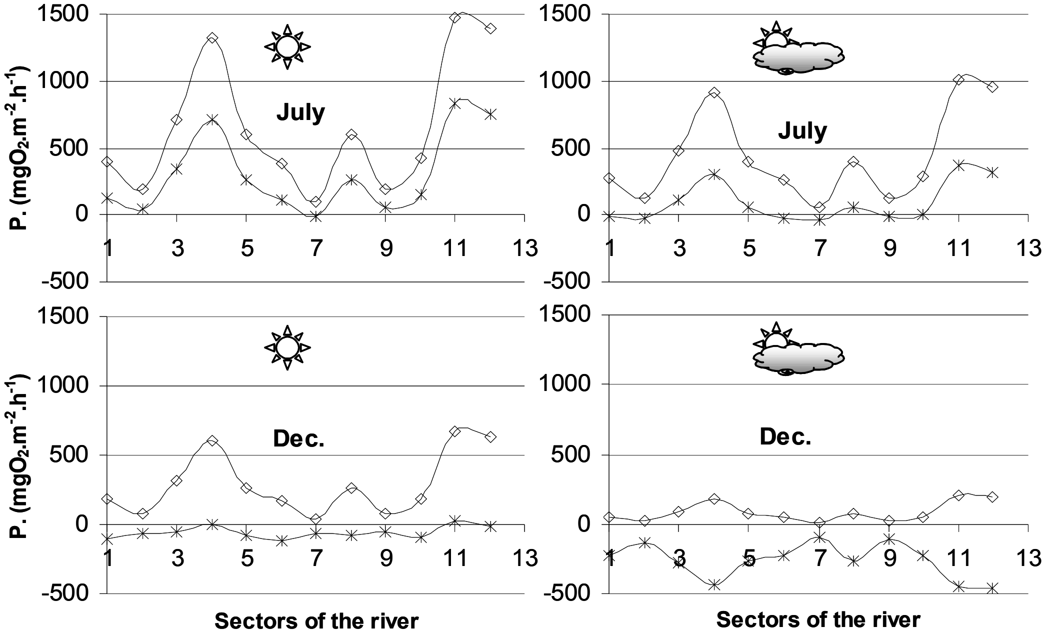

Figure 4. Pinsaguel site : Gross (GP) and Net (NP) production pattern. The cross-section of the river is represented by 12 sectors (8 m each) representing a river of 96 meter width.

The figure 5 shows the evolution of gross and net production on the cross-section during a summer day (from sunrise to noon) : the pattern of net production values is positive only for a part of the cross-section and when the sun is high. At sectors 2 to 7 of Gagnac site having a depth of 0.9 to 1.2 meter, the oxygen balance is always negative : as a consequence, for the cross-section, the value of net production per day is never positive.

The P3B model makes it possible to compare the differences between a sunny and a cloudy day (fig. 6) for two seasons (July and December) : the low level of irradiance increases the daily balance of oxygen deficit for the cross-section.

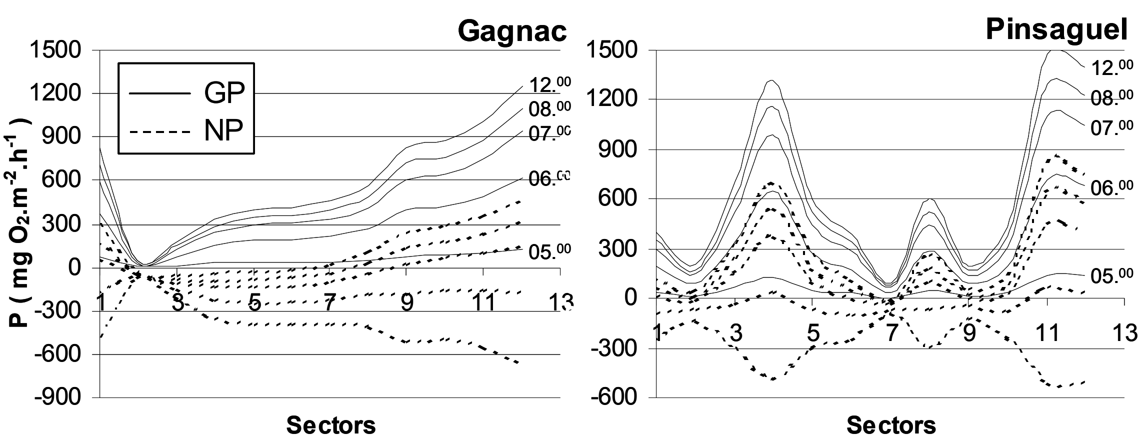

Figure 5. Gagnac and Pinsaguel sites : Evolution of the gross and net production pattern on a cross-section at different hours of the day (summer).

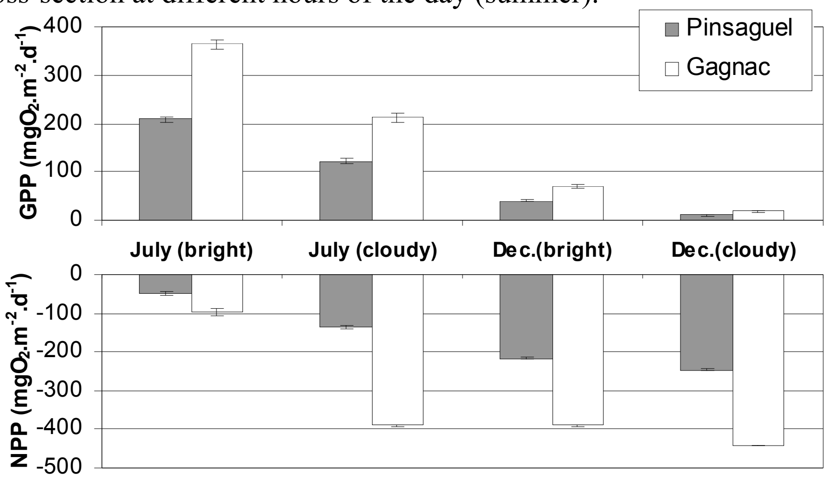

Figure 6. Mean of the gross and net production (± SE) in average value over the section at Gagnac and Pinsaguel

DISCUSSION

According to the calculations of the P3B model, the net daily rates of primary production show the values lower than or similar to the results that Mathey (2000) found (another way was used to analyze the pattern of dissolved oxygen in the river: *unpublished work made with Boehme's model based on the analysis of continuous recordings of dissolved oxygen, taking into account the re-aeration rate coefficient*). The P3B model allows i) to display the sectors of the river where the primary production is the best, ii) to point out the effects of light conditions on the daily balance of a cross-section.

Taking into account the estimation of respiration rate obtained from laboratory cultures (§ V.2) and from stones cropped in the river (§ V.3), a wide difference exists between the two types of periphyton community. In the river, the heterotrophic compartment is likely more represented, with a rise of the degradation activity linked to the carbon organic compounds: the combination of the various properties resulted in an important increase of the respiration rate of the periphyton unit.

For the algal compartment, the respiration rate is generally about 10% of Pmax (Bunt 1965, Smith 1977, Capblancq, 1982) corresponding to the results obtained from cultures (9% for young algal mat to 21% for 35 day old culture). Thus, considering the periphyton assemblage of the river, the heterotrophic activity could represent from 20 to 60 % of the Pmax rate.

Consequently, most of the time, the balance of dissolved oxygen tends to become negative in this river, particularly because of a degradation in water quality of river near Toulouse that enhances the heterotrophic activity. But dissolved oxygen balance in the river will be influenced by the re-aeration coefficient coming from the water velocity, depending also on temperature, photosynthetic release from macrophytes, chemical and biochemical reduction, and exchange with the atmosphere (Parkhill & Gulliver 1999).

Variations of pH and dissolved oxygen around the gravel bar covered by a periphytic biofilm, downstream from Toulouse, show the intensity of metabolic activities associated with the biofilm growing in the very shallow littoral areas (Dauta *et al.* 1999, Ameziane *et al.* 2002), as yet observed by Neal *et al.* (1997) : the high photosynthetic activity results in carbon dioxide depletion with a concomitant change to higher pH, oxygen enrichment and depletion of dissolved silica in the water ecosystem.

From the numerous investigations of periphyton seasonality (Cox 1990, Biggs 1996,) the generalized syntheses concluded that algal communities respond to seasonal variations in flow regime, nutrient supply, grazers, light or temperature, the nutrient supply driving the biomass accrual (Francoeur *et al.* 1999). In the Garonne, as the concentrations of nutrients certainly do not limit the growth of the biofilm, other factors like hydrodynamics, water transparency and light become the principal factors that control the dynamics of periphyton communities. Primarily, the daily net production appears to be negative, which is contradicted by a high epilithic biomass. The P3B model simulation can explain the results obtained by Mathey (2000) : it is perfectly clear that the rate of respiration of the unit (algae + bacteria) colonizing the riverbed, approximately 40 to 60 % of the value of algal Pmax, generates the heterotrophic functioning of the river.

To be really in accordance with biologic assumptions and rationales, especially to compare summer and winter case, the accuracy of calculations could be better by taking into account the temperature dependence of the photosynthesis and respiration rate.

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