Verh. Internat. Verein. Limnol.	23	1287–1293	Stuttgart, Oktober 1988

Primary production in the River Meuse (Belgium)

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With 4 figures and 2 tables in the text

Introduction

Different sites in the River Meuse, a large lowland river flowing through France, Belgium and the Netherlands, have been studied during two years, 1983 and 1984, with special reference to phytoplanktonic production. The sites considered in this paper are located in two reaches of the river; the upper part of the river is relatively unpolluted, while the downstream reach is affected by diverse urban and industrial pollutions.

Biomass and productivity in the upper part of the River Meuse are treated elsewhere in full details (Descy et al., in press). The studies carried out in the downstream part allow some comparison between the two sites, as well as with some other large European rivers.

Material and methods

The River Meuse in Belgium is a regulated river: its main characteristics have been presented e.g. in Descy & Mouvet (1984). The two sites considered are located as follows (Fig. 1): Site 1 is located km 490 to km 505 away from the source of the river; the second reach extends from km 550 to km 565.

The main differences between the two sites lie in hydrology and morphometry (see Table 1).

With these characteristics and owing to the low water transparency, the River Meuse almost exclusively supports planktonic primary production (macrophytes are nearly absent and periphyton occupy a very small littoral zone).

Water analyses and production measurements were carried out with a rather high frequency (once a week, or every two weeks in summer) in the two parts of the river during 1983 and 1984. Atmospheric irradiance data were provided by the Belgian Meteorological Institute; light propagation in the water column was calculated from the mean extinction coefficient, determined with a silicium photocell fitted with three filters (Vollenweider 1974). Chlorophyll-a was measured at first using the acetone method (Lorenzen 1967) and checked subsequently with the methanol method (Marker 1972, Marker et al. 1980): similar results were obtained by the two methods.

Phytoplankton *in situ* photosynthesis was measured by the oxygen light and dark bottle technique (with exposure periods of 4 to 7 hours); some ^{14}C measurements allowed the determination of a PQ = 1.25 (Descy et al., in press). Calculations of daily productions were made using a formulation similar to Vollenweider's equation and by determining Popt and Ik by the best fit to the measured values. Then, daily production (DP) per m^2 was calculated from the daily evolution of irradiance, by the complete numerical integration of the equation:

$$DP = \int_o^d \int_r^s 2\,\text{Popt}\,\frac{I(z,t)/2\,Ik}{1 + (I(z,t)/2\,Ik)^2}\,dt\,dz$$

where r = time of sunrise, s = time of sunset, I(z,t) = PAR at time t and depth z and d = depth of the water column.

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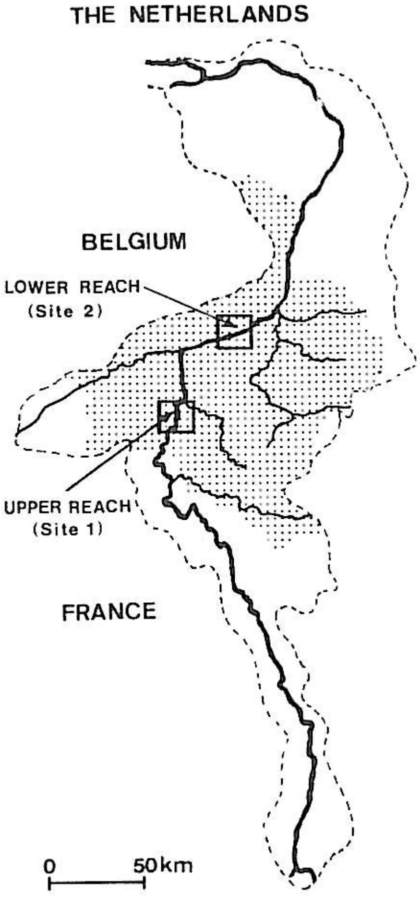

Fig. 1. Map of the River Meuse basin; the Belgian part lies in the shaded area.

Table 1. Physical characteristics of the two studied reaches of the River Meuse.

	Site 1	Site 2
Mean annual discharge	134 $m^3 \cdot s^{-1}$ (15–1500 $m^3 \cdot s^{-1}$)	215 $m^3 \cdot s^{-1}$ (25–2000 $m^3 \cdot s^{-1}$)
Width	100 m	120 m
Depth	3.20 m	5 m
Light extinction coefficient	1.8 m^{-1}	2.5 m^{-1}
Mean annual temperature	13.2 °C (1–27 °C)	12.1 °C (0.5–25 °C)

Results

Compared to the upstream relatively unpolluted site, the downstream reach is influenced by some domestic effluents and by industrial pollution. The main changes of water quality are:

1. an increase of organic pollution and eutrophication, shown by a greater concentration of DOC, a larger range of variation of dissolved oxygen concentration and large concentrations of NH_4^+, NO_2^- and P (FRP and total P);
2. an increase of conductivity and some major elements concentrations: the ions concerned are mainly Na^+, Cl^- and SO_4^{2-};
3. a decrease of water transparency, mainly due to fine suspended materials released by quarries or due to resuspension of bottom sediments.

In the two studied reaches, the water transparency is conspicuously one of the most important factors likely to control primary production: summer values of the extinction

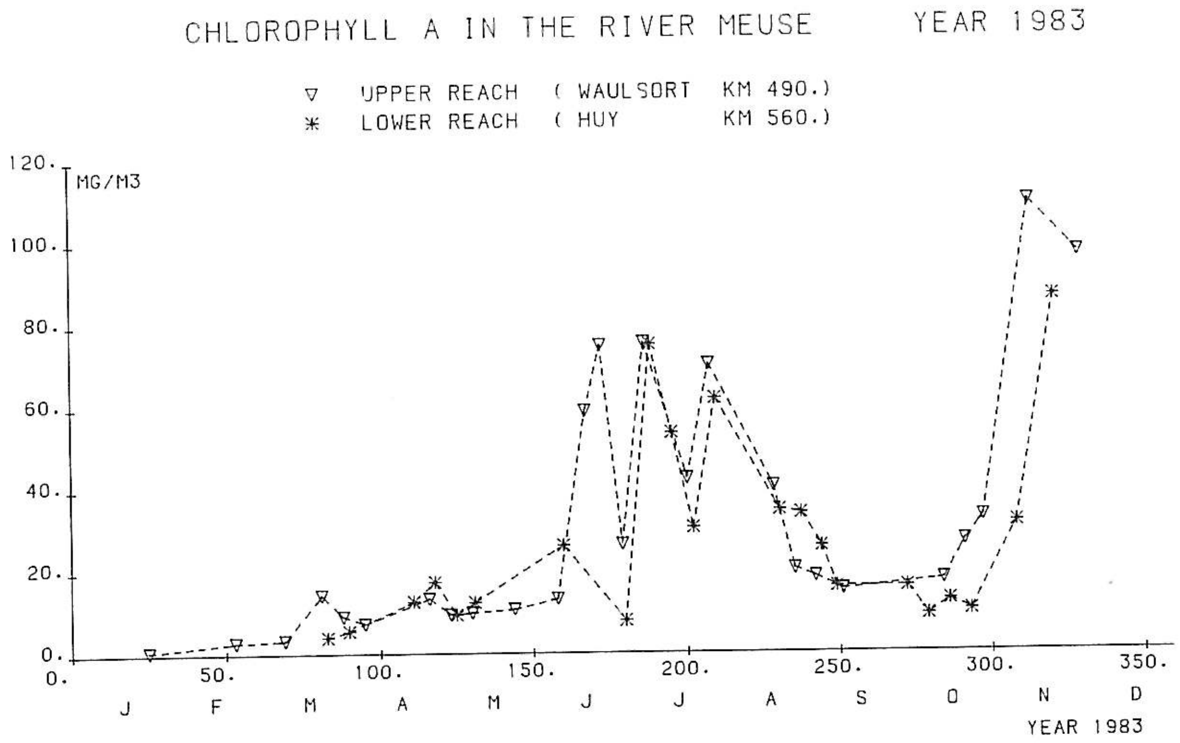

Fig. 2. Evolution of chlorophyll-a in the River Meuse in the two studied reaches during 1983.

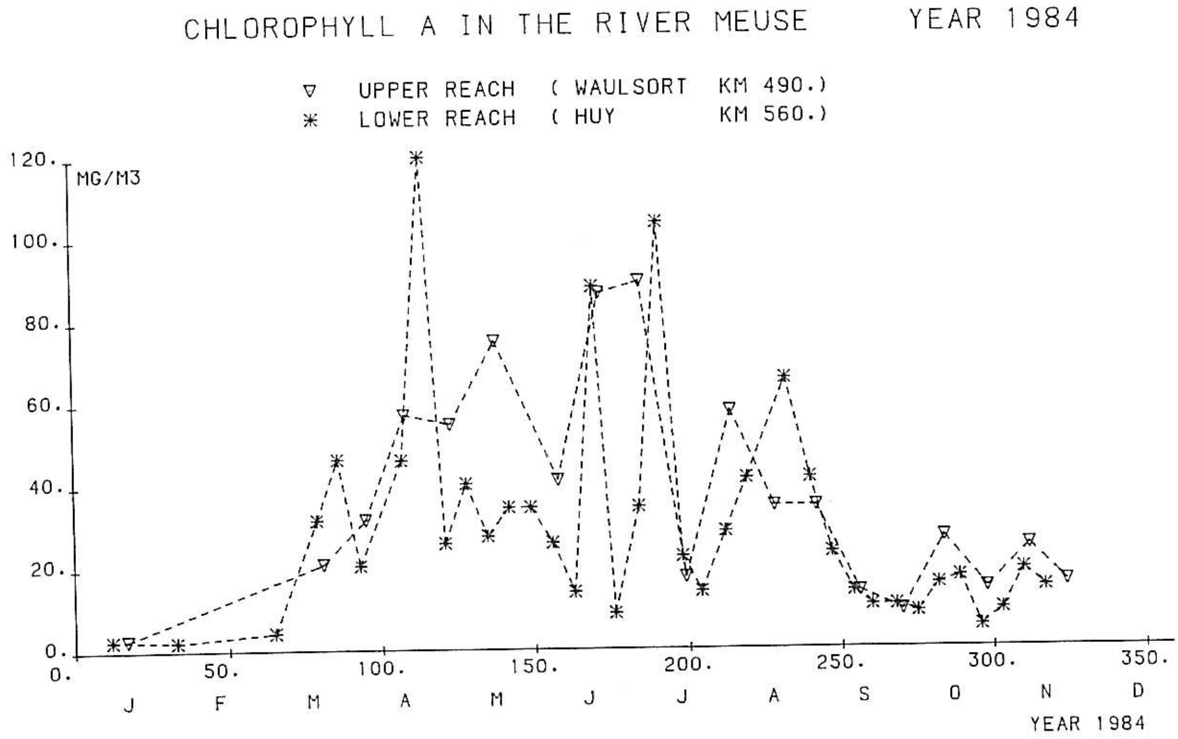

Fig. 3. Evolution of chlorophyll-a in the River Meuse in the two studied reaches during 1984.

coefficient range between 2.0 and 3.5 m^{-1}, so that the photic depth is limited to a fraction of the water column varying from 2.3 m to 1.3 m. In fact, the larger fraction of the photosynthesic activity occurs down to -1 m or -1.5 m.

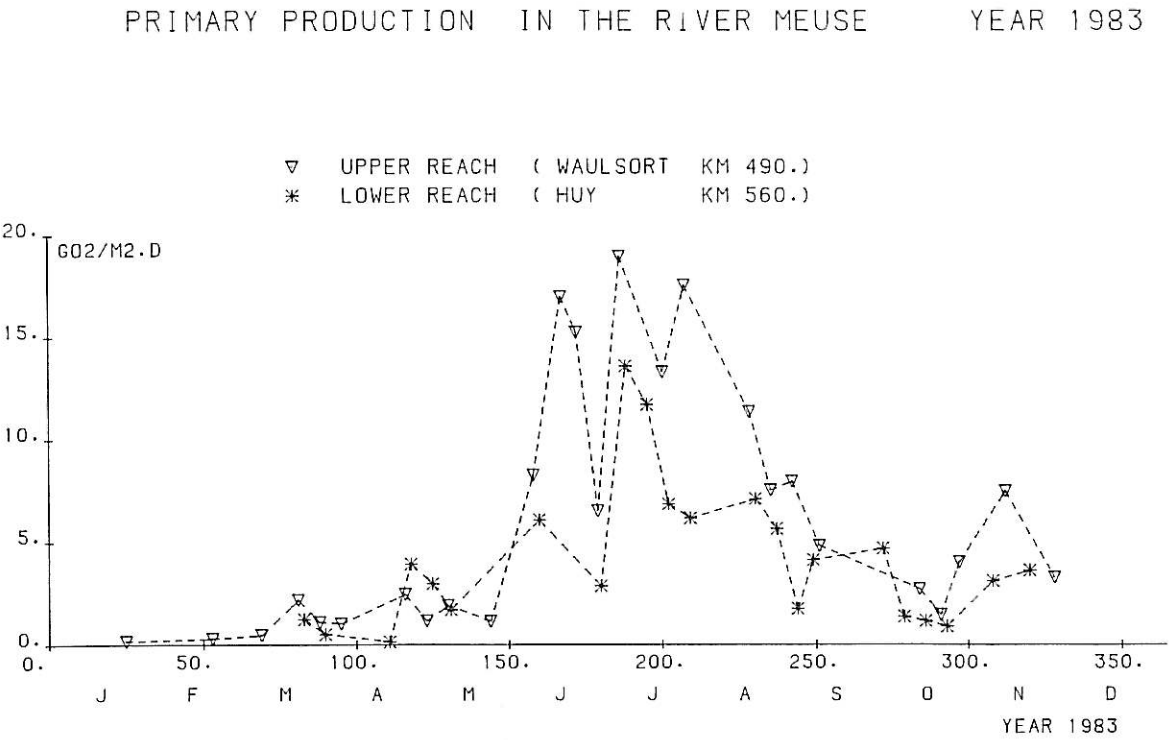

Fig. 4. Evolution of phytoplanktonic daily production in the River Meuse, in the two studied reaches, 1983.

Inorganic N and FRP do not exhibit large seasonal variations and are never depleted in any part of the river: this indicates that they are not limiting factors for phytoplankton growth. Silica presents larger variations due to consumption by actively growing diatoms: concentrations usually about 5 mg $\cdot$ l^{-1} Si may be reduced to 0.1 mg $\cdot$ l^{-1} Si immediately after a diatom bloom. However, considering large Si-inputs from the watershed, a limitation of diatoms growth does not seem likely.

The composition of the phytoplankton of the River Meuse has been described elsewhere (see Descy 1983 and Descy, 1987): the dominant components are centric diatoms (genera *Cyclotella* and *Stephanodiscus*) and various Chlorococcales.

The phytoplankton biomass (Figs. 2, 3) presents strong seasonal variations, with low values in winter (about 3 mg chlorophyll-a $\cdot$ m^{-3}) and the highest values in summer or autumn (90 and 121.5 mg Chl-a $\cdot$ m^{-3} in 1983). The evolution of the biomass is clearly related to hydrology, light and temperature as no nutrient limitation is likely to occur.

The profiles of primary production (Fig. 4) are very similar to the biomass profiles. In the upper part of the Belgian Meuse, measured gross daily production ranged from 0.05 to 5.78 g C $\cdot$ m^{-2} $\cdot$ d^{-1} in 1983, and from 0.18 to 4.35 g C $\cdot$ m^{-2} $\cdot$ d^{-1} in 1984. For the lower part of the Belgian Meuse, measured GP varies between 0.08 and 5.52 g C $\cdot$ m^{-2} $\cdot$ d^{-1} in 1983 (conversions from O_2 production to C assimilation made with PQ = 1.25).

The annual production has been computed from simulations of production throughout the year 1983. The value for the upper Belgian Meuse is 590 g C $\cdot$ m^{-2} $\cdot$ y^{-1}, vs. 314 g C $\cdot$ m^{-2} $\cdot$ y^{-1} for the lower part.

Table 2. Summary of measurements of planktonic productivity in some European large rivers.

River	Reference	Mean annual GP $gC \cdot m^{-2} \cdot d^{-1}$	Minimal GP $gC \cdot m^{-2} \cdot d^{-1}$	Maximal GP $gC \cdot m^{-2} d^{-1}$	Maximal biomass
Loire (France)	Champ (1980)	–	0.041*	22.7*	10 $gC \cdot m^{-3}$
	Billen et al. (1984 b)	1.51	0.05	3.9	158 mg Chl. $a \cdot m^{-3}$
Lot (France)	Capblancq & Dauta (1978)	0.75	0.068	2.32	15 mg Chl. $a \cdot m^{-3}$
Oise (France)	Billen et al. (1984 a)	0.82 (1981)	–	–	70 mg Chl. $a \cdot m^{-3}$
		0.96 (1982)	0.07	2.7	101 mg Chl. $a \cdot m^{-3}$
Seine (France)	Bordet (1980)	–	(0.3)	4.40	85 mg Chl. $a \cdot m^{-3}$
Thames (England)	Wetzel (1975)	1.44	0.006	4.50	197 mg Chl. $a \cdot m^{-3}$
	Lack & Berrie (1976) Westlake (1980)	1.26 (NP)	–	–	–
Kennet (England)	Lack & Berrie (1976) Westlake (1980)	−0.008 (NP)	0.03	0.42	62 mg Chl. $a \cdot m^{-3}$
Bure (England)	Moss et al. (1984)	–	–	–	400 mg Chl. $a \cdot m^{-3}$
Wye (Eengland)	Jones (1984)	–	–	–	137 (400) mg Chl. $a \cdot m^{-3}$
Neckar (Germany)	Pinter & Backhaus (1984)	–	–	OPL:8.4 mg $C \cdot m^{-3} \cdot h^{-1}$	113 mg Chl. $a \cdot m^{-3}$
Rhine (Germany)	Friedrich & Muller (1984)	–	–	OPL:7 mg $C \cdot m^{-3} \cdot h^{-1}$	185 mg Chl. $a \cdot m^{-3}$
	Wetzel (1975)	0.6	–	–	–
Danube (Czechoslovakia)	Ertl & Juris (1967)	0.66	0	4.05	–
Dnieper (USSR)	Polishchuk & Tomnitskiy (1985)	–	0.63 (1959–1964)	1.47	–
			0.67 (1981)	1.41	3.296 $g \cdot m^{-3}$
Verevchikha (USSR)	Polishchuk & Tomnitskiy (1985)	–	0.14	1.20	0.444 $g \cdot m^{-3}$
Escaut (Belgium)	Billen et al. (1984 b)	1.18	0.07	4.5	155 mg Chl. $a \cdot m^{-3}$
Meuse (Belgium)	Descy et al. (this paper)	1.62 (1983)	0.05	5.78	121.5 mg Chl. $a \cdot m^{-3}$
		1.68 (1984)	0.18	4.35	89.6 mg Chl. $a \cdot m^{-3}$

GP = gross production.

NP = net production; C production calculated with PQ = 1.25, when only oxygen measurements were available.

* calculated over a 1.20 m depth.

OPL: oxygen production under laboratory conditions.

Discussion

Most of the time, the phytoplankton biomass of the two parts of the River Meuse follows the same pattern and reaches similar levels; the peaks observed in 1984 at site 2 are probably due to non-stationary conditions occurring somewhere between the two sites. Descy & Mouvet (1984) reported severe reductions of chlorophyll-a concentrations at some locations in the River Meuse, but they were observed in a downstream zone, submitted to heavy industrial pollution.

On the other hand, primary production is lower at the second site. As similar light-saturated rates of photosynthesis are observed at the two sites, this lower production can be attributed to the reduction of the euphotic depth. The fact that chlorophyll-a concentrations remain at similar levels shows that the reduced productivity at site 2 is sufficient to maintain the algal biomass coming from the upstream part.

As shown in Table 2, which summarizes data from the literature, gross production in the River Meuse lies in the maximum of the range reported for other European large rivers. More particularly, as far as conclusions can be drawn from the relatively few values of annual GP available for large rivers when compared to lakes, the values of the upper Belgian Meuse seem to reach a maximum for planktonic production in temperate water bodies, which lies around 1.4—1.6 g C $\cdot$ m^{-2} for the mean daily gross production. Indeed, similar values were observed in large nutrient-rich rivers, like the River Loire (France), the River Thames (England) and the River Scheldt (Belgium). Maximal biomass estimates are more frequent: in many European rivers, they are typical of eutrophicated waters and usually range between 90 and 200 mg chl-a $\cdot$ m^{-3} (see Table 2).

Furthermore, all these eutrophicated lowland rivers exhibit similar composition of the phytoplankton communities, dominated by centric diatoms and by Chlorococcales, with maximal cell densities often largely exceeding 10,000 cells $\cdot$ ml^{-1}, even reaching 100,000 cells $\cdot$ ml^{-1} during blooms (Descy 1987). Therefore, it is likely that GP values for River Rhine and River Danube should be reestimated on the basis of more recent evaluations, as eutrophication has been growing during the past two decades (Friedrich & Muller 1984).

If phytoplankton gross production is similar in all these rivers, the differences in maximal densities and biomass can be attributed to physical features, as water transparency depending on concentration of suspended matter, depth of the channel and flow rate. More particularly, the effect of flow rate on phytoplankton biomass can be described by a balance between the "dilution rate" by the lateral water inputs vs growth rate of the phytoplankton (Descy et al., in press).

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