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Eric Chauvet, Aude Fabre. Dynamics of seston constituents in the Ariège and Garonne rivers (France). *Hydrobiologia*, 1990, 192 (2), pp.183-190. 10.1007/BF00006013 . hal-01264311

HAL Id: hal-01264311

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To link to this article : DOI : 10.1007/BF00006013
URL : <http://dx.doi.org/10.1007/BF00006013>

<p>To cite this version : Chauvet, Eric and Fabre, A. <i>Dynamics of seston constituents in the Ariège and Garonne rivers (France)</i>. (1990) <i>Hydrobiologia</i>, vol.192 (n°2). pp.183-190. ISSN 0018-8158</p>

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Dynamics of seston constituents in the Ariège and Garonne rivers (France)

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Key words: seston, particulate organic carbon, particulate phosphorus, algal pigments, river

Abstract

Water contents of suspended matter, algal pigments, particulate organic carbon and particulate phosphorus were measured in the rivers Garonne (2 sites) and Ariège (1 site) throughout an annual cycle. The general trend of the parameters was similar at the three sites. Depending on the sites, the period of algal growth (chlorophyll *a* + phaeopigments $> 25 \mu\text{g l}^{-1}$), lasted from two to six weeks in August–September. The algal peaks reached 50 to $90 \mu\text{g l}^{-1}$ of total pigments. High contents of particulate organic carbon ($> 2 \text{ mg l}^{-1}$) occurred at the end of summer (coinciding with algal growth), and during the November and May floods. In summer 50–75% of the suspended matter was organic, in spring this was 10 times less. The high linear correlation between particulate organic carbon and pigment contents ($r = 0.87$; $P = 0.0001$) suggested an algal origin of at least part of the particulate carbon. Algal carbon was minor in the annual fluxes of particulate carbon (25 to 39% depending on the sites), but relatively high in comparison with other rivers. The mean particulate phosphorus content calculated over the year was $24 \mu\text{g l}^{-1}$; it varied from $15 \mu\text{g l}^{-1}$ during the high water period to $28 \mu\text{g l}^{-1}$ during the low water period. Likewise the percentage of particulate phosphorus in the suspended matter varied from 0.17 to 0.40. A negative linear correlation existed between particulate phosphorus content and specific discharge ($r = -0.46$; $P = 0.0001$).

The very marked seasonal trend of the parameters and the interactions led us to differentiate two modes of the rivers' functioning: a 'hydrologic' phase and a 'biological' phase. The hydrologic phase (high water) was dominated by the processes of erosion and transfer over the whole catchment area and the flood plain, while the biological phase was characterized by a high primary production in the river bed.

Introduction

For several years research has been carried out to improve the understanding of the biogeochemical cycles in rivers. While the first studies were mainly concerned with the geochemistry of large rivers (Livingstone, 1963), more recently interest has

developed with regard to the carbon, nitrogen and phosphorus cycles (Meybeck, 1982) and particularly to their interactions (Richey, 1983). These studies, often assessing the exports to the oceans and lakes (Cahill, 1977; Martin & Meybeck, 1979; Meybeck, 1982; Ryding, 1988) and to the allochthonous and autochthonous origins of the

organic matter (Liaw & Mc Crimmon, 1977; Richey *et al.*, 1980; Dessery *et al.*, 1984a), rarely associated element cycles and ecological functioning (Dessery *et al.*, 1984b). Budgets of carbon and organic matter were studied in the downstream part of the Garonne (Cauwet & Martin, 1982; Relexans & Etcheber, 1982), while in the middle part of the river research was mainly oriented geochemically (Probst, 1985).

In this paper we describe the seasonal trend of three seston parameters at three sites of the Garonne basin: algal pigments (PIG), particulate organic carbon (POC), and particulate phosphorus (PP). Their relations with the suspended matter (SM) and the specific discharge (SD) are also investigated. In conclusion we present a typology of these rivers based on the importance of the relations between the river and its environment.

Sites, material and methods

Two sites on the Garonne were chosen, one 2 km upstream of the confluent with the Ariège, the other 8 km downstream of the confluent. The Ariège site is located 2 km upstream of the confluent (altitude 140 m). The rivers have their sources in the Pyrenees and present a nival transitional regime with maximum discharges in May-June (snow melting). The low water period generally lasts from August to October but may continue longer. Spring floods regularly exceed $500 \text{ m}^3 \text{ s}^{-1}$ and the low water discharges can fall to $50 \text{ m}^3 \text{ s}^{-1}$ (the downstream Garonne site). The Ariège basin area is 3450 km^2 , the Garonne upstream basin area is 6530 km^2 . Successively they are formed of plutonic rocks, carbonated rocks and detritic deposits. In their upper part the landscape consists of beech and coniferous forests, whilst agricultural activity predominates in the lower parts. A degraded alluvial forest covers the banks of these rivers.

Throughout 1986 samples were taken every week from May to October and every two weeks for the rest of the year, i.e. 33 samples per site. Ten litres of water were collected from each site. In the

laboratory the water was homogenized, prefiltered through a 1 mm sieve then filtered on preheated Whatman GF/C. Chlorophyll *a* and phaeopigments were extracted with boiling methanol; pigment contents were calculated with Lorenzen's (1967) spectrophotometric equations. The sum of these pigments is PIG. Suspended matter was measured after drying at $80 \text{ }^\circ\text{C}$ for 24 hours. Particulate organic carbon was measured on filter portions after mineralization in sealed vials and by I.R. determination of CO_2 (Kontron apparatus). Particulate phosphorus was measured by treatment of filter portions with H_2SO_4 and persulphate at $120 \text{ }^\circ\text{C}$, and using molybdenum blue, and ascorbic acid as a reducing agent (Golterman *et al.*, 1978, methods 5.7.3 + 5.6.2). Specific discharges were calculated from the flow gauge measurements. The statistical methods (correlation, regression, principal component analysis, cluster analysis, and analysis of variance) were taken from the SAS Software (SAS Institute Inc., 1982).

Results

Changes in the variables

The changes in pigments, particulate organic carbon and particulate phosphorus contents are shown in Fig. 1. The seasonal trend of pigment concentrations was similar at the three sites, but the contents were generally less at the upstream Garonne site. The summer increase was very marked with highest values at the beginning of September 1986. In the Ariège the period of algal growth (total pigments $> 25 \mu\text{g l}^{-1}$) lasted 6 weeks from August to September, at the downstream Garonne site 4 weeks, and at the upstream site approximately 2 weeks. The maxima were $90 \mu\text{g l}^{-1}$ for the Ariège, $50 \mu\text{g l}^{-1}$ for the Garonne downstream and $32 \mu\text{g l}^{-1}$ for the Garonne upstream in September 1986. Lesser peaks were also observed at the three sites during two periods of the year: April-May and late June-early July.

The changes in POC concentrations were rela-

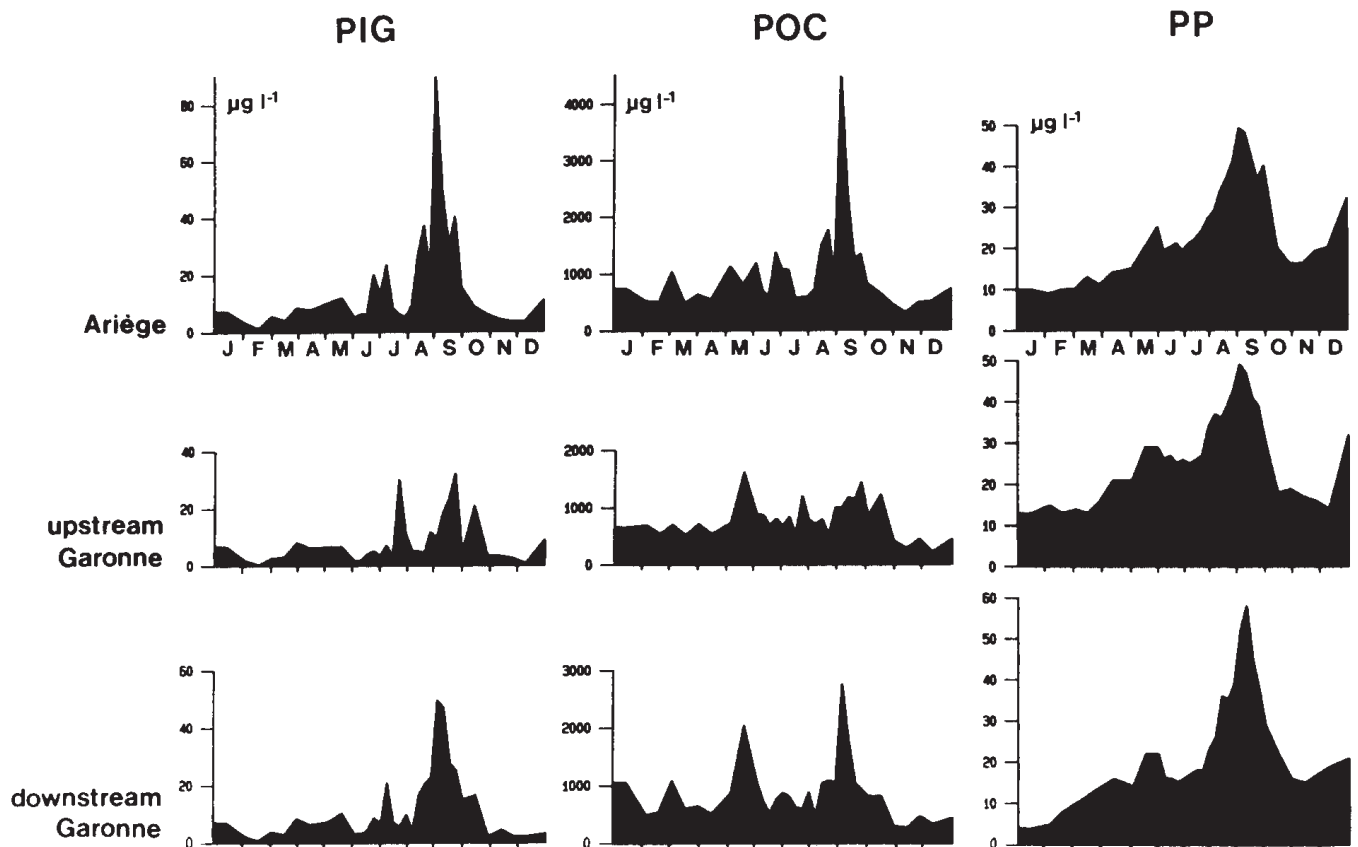


Fig. 1. Variations of pigments, particulate organic carbon, and particulate phosphorus contents at the three rivers sites during 1986.

tively similar at the three sites; but as in the case of the pigments, the peaks were not so high at the upstream Garonne site. The annual cycle was characterized by high contents ($> 2 \text{ mg l}^{-1}$) at the end of summer coinciding with algal growth in August-September, and by high concentrations in May. These high spring contents could be as high as those in summer, which was not the case for the algal pigment concentrations which were always higher in summer.

The particulate phosphorus showed a very pronounced seasonal trend (Fig. 1). The low values noted from January to March were followed from April to mid-July by high values, which then increased considerably until mid-September. This pattern was the same for the three sites. The particulate phosphorus concentrations varied between 4 to $58 \text{ } \mu\text{g l}^{-1}$.

Relations between variables

The POC contents at the three sites taken as a whole did not appear to be significantly correlated with the specific discharges ($r = -0.025$; $P = 0.804$), but were correlated with SM ($r = 0.36$; $P = 0.0003$). Moreover the carbon fraction of SM was negatively correlated with the specific discharge ($r = -0.69$; $P = 0.0001$) and varied during the year; the carbon represented 2 to 3% of the SM flushed during the May floods, while it was 20 to 30% of the seston in summer. Thus the summer SM consisted of approximately 50 to 75% of organic matter (based on mean carbon content in organic matter of 40%). At the three sites as a whole the algal pigment concentration was negatively correlated with the specific discharge ($r = -0.33$; $P = 0.0008$). The very high linear correlation between the POC and PIG contents at the three sites indicated the importance of

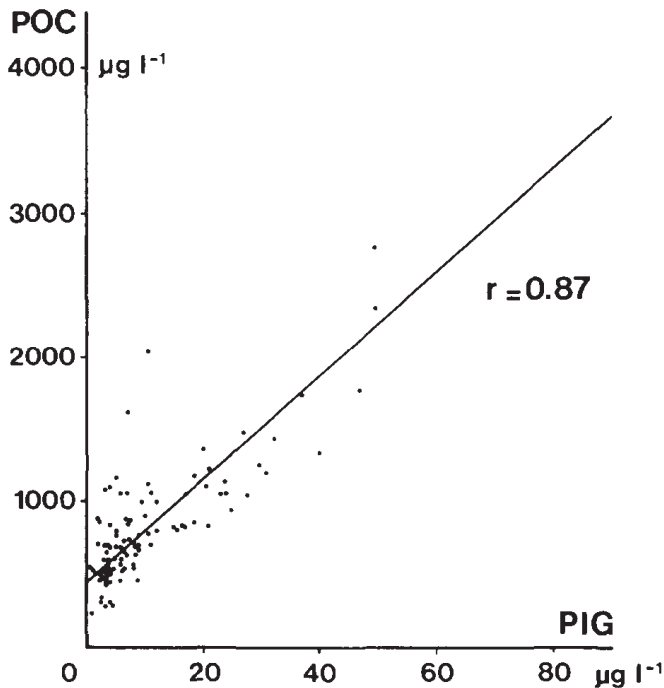


Fig. 2. Linear correlation between concentrations of particulate organic carbon and pigments at the three sites taken as a whole ($r = 0.87$; $P = 0.0001$).

carbon of algal origin in the POC pool ($r = 0.87$; $P = 0.0001$). The slope represented the quantity of algal carbon corresponding to a concentration of photosynthetic pigments (Fig. 2). This slope

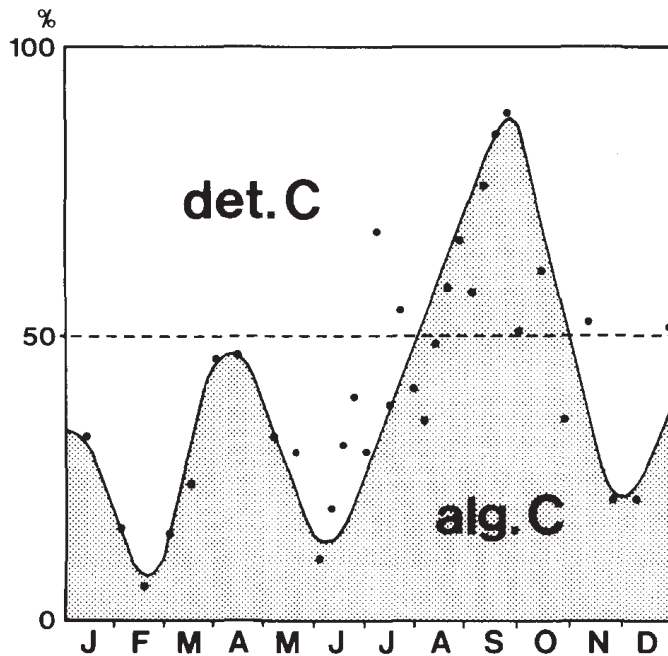


Fig. 3. Variation in mean algal and detrital carbon percentage of particulate organic carbon at the three sites during 1986 (curve fitted by eye).

varied between 28.1 at the upstream Garonne site and 39.8 at the downstream Garonne site. At the three sites the average slope was 36. Supposing the ratio algal POC/total pigments to be constant throughout the year and equal to 36, the algal carbon and detrital organic carbon parts could be calculated; the latter corresponded to the difference between the total POC and the algal POC. During the year the proportion of the two carbon forms varied considerably (Fig. 3). On the average the detrital C predominated, except during the summer months (August-September) when the algal C represented 50 to 90% of the total organic carbon.

For all 99 observations, PP was positively correlated with both POC and PIG and negatively with SD, while no linear correlation existed with SM (Table 1). However, the partial correlation between PP and SM became highly significant ($r_{ij.k} = 0.49$; $P = 0.0001$) when SD was taken as a constant. This showed the predominant role of discharges in the relations between the examined variables. This result combined with the very pronounced seasonal pattern of the parameters suggested that it was preferable to look for more homogeneous sub-groups of observations. Therefore we carried out a PCA on the observations as a whole using PP, PIG, POC, SM and SD as variables. The factorial scores according to F1 and F2 were then submitted to the FASTCLUS procedure which performed a disjoint cluster analysis. After this treatment we eliminated 14

Table 1. Linear correlations and associated probabilities between particulate phosphorus and specific discharge, suspended matter, particulate organic carbon and pigments (the high water and low water periods are defined by the clustering method).

		SD	SM	POC	PIG
Year ($n = 99$)	r	-0.46	-0.03	0.56	0.66
	P	0.0001	0.799	0.0001	0.0001
High water ($n = 33$)	r	-0.31	0.06	0.12	0.10
	P	0.079	0.733	0.50	0.59
Low water ($n = 52$)	r	-0.30	0.40	0.60	0.51
	P	0.028	0.003	0.0001	0.0001

Table 2. Means of specific discharges, of seston parameters, and of the proportion of particulate phosphorus in suspended matter. P ANOVA between periods defined by the clustering method.

	Year	High water	Low water	P ANOVA
SD ($1 \text{ s}^{-1} \text{ km}^{-2}$)	12.87	17.80	6.18	0.0001
SM (mg l^{-1})	11.39	9.70	7.42	0.0003
POC ($\mu\text{g l}^{-1}$)	869	661	796	0.0438
PIG ($\mu\text{g l}^{-1}$)	11.67	5.23	13.00	0.0001
PP ($\mu\text{g l}^{-1}$)	24.25	15.33	28.35	0.0001
PP/SM (%)	0.29	0.17	0.40	0.0001

observations corresponding to the extreme values of one or several parameters (SD, SM or PIG) and related to particular conditions (flood or algal peak) which could only be the subject of special research. From this we retained two main groups of observations: the first group was marked by both high SD and high SM values. It consisted of 33 observations from January to April, plus the month of June. This group corresponded to the high water period which, in a temperate climate, takes place partly in winter and in spring, but did not include the observations of high floods in May. The second group was characterized by high PP, as well as POC and PIG contents. It consisted of 52 observations between July and December and corresponded to the low water period. These two groups differed significantly for the variables taken as a whole, but also for the proportion of PP in SM which was definitely greater in the low water period (Table 2). During the high water period PP did not fit in linearly with

Table 3. Annual flux of seston elements on the three river sites (t yr^{-1}).

	Ariège	Upstream Garonne	Downstream Garonne
SM	34 000	49 100	86 400
Algal C	580	560	1 140
Detrital C	900	1 650	2 980
Total POC	1 480	2 210	4 120
Part. Phosphorus	32.5	61.2	75.3

SD, SM, POC and PIG. On the contrary, during the low water period there were significant and positive linear correlations with SM, POC and PIG and a negative one with SD (Table 1). However, the partial correlations between PP and SM when POC or PIG were taken as constant became non-significant ($r_{ij.k} = 0.13$ and 0.17 respectively) which suggested the importance of PP of algal origin.

Discussion

The pigment concentrations observed in the rivers Garonne and Ariège were lower than those observed in the river Loire (Khalanski & Renon, 1977), but they were the same as those noted by Dessery *et al.* (1984a) in the rivers Vire, Oise and Seine. The maxima were generally inferior to those observed by Dauta (1978) at the Garonne sites located downstream a large reservoir. Moreover Relexans et Etcheber (1982) noted for the Garonne, in the upper part of the Gironde estuary, mean concentrations of total pigments of $28 \mu\text{g l}^{-1}$ from April to November; at our sites, located further upstream, we observed means from 9 to $22 \mu\text{g l}^{-1}$ for the same period. Because of the low water levels during the algal growth period, the flux of algal carbon remained relatively minor in the annual POC budget (Table 3). It represented 25% of the annual flux of particulate carbon in the Garonne, but this proportion reached 39% in the Ariège. This latter site was nevertheless influenced by a reservoir located several kilometers upstream, where conditions for phytoplankton development were favourable. The importance of algal carbon in the annual carbon budgets at our three sites was greater than in the Vire (9–17%) and the same as in the Oise (32%, Dessery *et al.*, 1984a). In a 4-km section of the Garonne between the upstream and downstream sites, the direct input of leaf litter coming from the riparian forest has been estimated at 25 t yr^{-1} of allochthonous particulate carbon (Chauvet & Jean-Louis, 1988). Cumulated over the whole of the hydrographic network, these inputs of terrestrial origin probably represented a

major part of the 2980 tons of particulate carbon annually carried along to the downstream Garonne site (Table 3).

The mean concentration in particulate phosphorus in the Garonne and Ariège ($24 \mu\text{g l}^{-1}$) was lower than that found by El-Habr & Golterman (1987) in the Rhône ($60 \mu\text{g l}^{-1}$). The PP content in suspended matter at our sites (0.29%) was relatively high in comparison with the 0.115% given by Martin & Meybeck (1979) or estimated from PP and SM means given by El-Habr & Golterman (1987). Probst (1985) noted values varying between 0.11% (high water period) and 0.21% (low water period) in a small farm catchment area. In our study the seasonal variations were still more pronounced: 0.17 and 0.40% in periods of high and low water. Moreover the high water period, when PP did not linearly fit in with the other parameters, contrasted with the low water period when the linear correlations were strong. These observations resulted from the river's two different modes of functioning. In the high water period the suspended matter or the particulate phosphorus, of which SM was the vector, originated both in- and outside the river. The SM and the PP came from deposits on the river bed and from soil particles washed from the banks or exported from the upstream catchment area. So the total phosphorus contents of the Garonne deposits or the riverine soils susceptible to be resuspended varied between 1000 and $3500 \mu\text{g g}^{-1}$ (unpublished data). Moreover, in the high water period, a same specific discharge corresponded to snow melting at an altitude where forest predominated, or to rainfalls in rural areas lower down. In these conditions it was difficult to establish linear correlations between PP and SM or SD, particulate phosphorus in high water periods being the result of numerous interacting factors which were hard to control. On the contrary, in the low water period the river functioned much more independently of its catchment area, and an important part of PP was of algal origin; however, a part of phosphorus could come from apatite (Golterman, pers. comm.). Contrary to Cahill (1977) for total phosphorus or El-Habr & Golterman (1987) for

particulate phosphorus, we found a negative correlation between PP and SD. In the case of the low water period only, several results from lake ecology or pedology research can be mentioned:

a) Working on lake sediments several authors have shown that the resuspension of sediments due to the agitation of the waters by the wind led to orthophosphate solubilization (Andersen, 1974; Rippey, 1977; Ryding & Forsberg, 1977; Bates & Neafus, 1980; Fabre, 1988). This phenomenon was considered by several authors to be a cause of the eutrophication of some lakes through internal phosphate input. This input could come in part from the orthophosphate of the interstitial water of sediments, but also from adsorbed forms of clays, ferrous hydroxides or organic matter. Thus a slight increase in summer discharges caused the resuspension of sediments poor in phosphorus. This phenomenon is also controlled by the nature of the sediments as well as by the conditions of the resuspension of the sediments (Holdren & Armstrong, 1980; Lennox, 1984; Fabre, 1988).

b) The resuspension of sediments in water with a high pH led to the release of ortho-P initially in an adsorbed form (Lijklema, 1977; Rippey, 1977; Jacoby *et al.*, 1982; Fabre, 1988). The waters of the Garonne and the Ariège had a pH of about 8.5 in the low water period which, as a result, provoked the solubilization of a part of the mineral phosphorus.

c) It has been established that the desiccation of a soil (Bartlett & James, 1980; Haynes & Swift, 1985; Sparling *et al.*, 1985) or of a lake sediment (Fabre, 1988) led to the release of orthophosphate, therefore to the impoverishment of soil particles or sediments when they were resuspended in the water. Thus, in the case of lake sediments, 17% more ortho-P was released after the resuspension of a desiccated sediment in comparison with the same sediment kept wet (Fabre, 1988). Some authors tended to attribute this result to the lethal effect of desiccation on part of the microbial biomass (Sparling *et al.*, 1985) and algal biomass in the case of sediments, while others thought it to be the effect of a physico-chemical modification of soils (Bartlett & James,

1980; Haynes & Swift, 1985). Such a process could affect the sediments of the Garonne and Ariège, which emerged in the low water period and were desiccated by the sun.

The processes which led to the release of ortho-phosphate, coming partly from phosphorus adsorbed on clay, partly from P in ferrous hydroxides or included in the microbial or algal biomass, probably caused the decrease of P in suspended matter and, as a result, in particulate phosphorus. These processes were controlled by a slight rise of the discharges, which led to the resuspension of particles progressively becoming poor in phosphorus.

Conclusion

The rivers Garonne and Ariège are characterized by the existence of two very contrasting phases during the annual cycle. During the high water period the organic fraction of SM was low and essentially corresponded to detrital organic matter of differing origins. In the low water period SM was mainly organic and made up of planktonic algae. Thus the particulate phosphorus concentrations were linearly correlated with the other parameters in summer, while during the spring high water period no correlation could be established because of the complex origin of suspended matter and therefore of particulate phosphorus.

The spring period was strongly influenced by erosion and transport in the catchment and the flood plain. At the other extreme the low water period was dominated by biological processes limited to the river bed (primary production) and, to a lesser extent, by hydrologic phenomena. We could thus differentiate two periods: a 'hydrologic' phase and a 'biological' phase. It might be possible to establish a functioning typology of rivers in the biogeographical zones according to the relative importance of these two phases.

Acknowledgements

We are grateful to Dr. H. L. Golterman for his comments and suggestions on this paper. We

thank Mrs M. Escautier, A. M. Jean-Louis and M. F. Patau-Albertini for their assistance in the chemical analysis, and Mrs J. C. Golterman for her help with the English translation.

References

- Andersen, J. M., 1974. Nitrogen and phosphorus budgets and the role of sediments in six shallow Danish lakes. *Arch. Hydrobiol.* 74: 528–550.
- Bartlett, R. & B. James, 1980. Studying dried, stored soils samples – Some pitfalls. *Soil Sci. Soc. Am. J.* 44: 721–724.
- Bates, M. H. & N. J. E. Neafus, 1980. Phosphorus release from sediments from lake Carl Blackwell, Oklahoma. *Wat. Res.* 14: 1477–1481.
- Cahill, T., 1977. Forms and sediment associations of nutrients (C, N and P), pesticides and metals. Nutrient-P. In H. Shear, A. E. P. Watson (eds.), *The fluvial transport of sediment-associated nutrients and contaminants*. Proc. Internat. Joint Commiss. Workshop, Kitchener, Ontario: 163–180.
- Cauwet, G. & J. M. Martin, 1982. Organic carbon transported by French rivers. *Mitt. Geol. Paläont. Inst. Univ. Hamburg SCOPE/UNEP Sonderband Heft 52*. Hamburg Mai 1982: 475–481.
- Chauvet, E. & A. M. Jean-Louis, 1988. Production de litière de la ripisylve de la Garonne et apport au fleuve. *Acta Oecologica, Oecologia generalis* 9 (3): 265–279.
- Dauta, A., 1978. Evolution estivale du phytoplancton dans une retenue placée au confluent de deux rivières. *Cah. Lab. Montereau* 7: 33–40.
- Dessery, S., C. Dulac, J. M. Laurenceau & M. Meybeck, 1984a. Evolution du carbone organique particulaire 'algal' et 'détritique' dans trois rivières du Bassin Parisien. *Arch. Hydrobiol.* 100 (2): 235–260.
- Dessery, S., C. Lancelot & G. Billen, 1984b. Primary production and its fate in the storage basin of Méry-sur-Oise. *Verh. int. Ver. Limnol.* 22: 1504–1509.
- El-Habr, H. & H. L. Golterman, 1987. Input of nutrients and suspended matter into the Golfe du Lion and the Camargue by the river Rhône. *Sciences de l'Eau* 6: 393–402.
- Fabre, A., 1988. Experimental studies on some factors influencing phosphorus solubilization in connexion with the drawdown of a reservoir. *Hydrobiologia* 159 (2): 153–158.
- Golterman, H. L., R. S. Clymo & M. A. M. Ohnstad, 1978. Methods for physical and chemical analysis of fresh waters. *IBP Handbook n° 8*. Blackwell Sci. Publi., Oxford, 213 pp.
- Haynes, R. J. & R. S. Swift, 1985. Effects of air drying on the adsorption and desorption of phosphate and levels of extractable phosphate in a group of acid soils, New Zealand. *Geoderma* 25: 145–157.

- Holdren, G. C. & D. E. A. Armstrong, 1980. Factors affecting phosphorus release from intact lake sediment cores. *Envir. Sci. Technol.* 14: 79–87.
- Jacoby, J. M., D. D. Lynch, E. B. Welch & M. A. Perkins, 1982. Internal phosphorus loading in a shallow eutrophic lake. *Wat. Res.* 16: 911–919.
- Khalanski, M. & J. P. Renon, 1977. Evolution de la teneur en pigments phytoplanctoniques dans la Loire entre Dampierre en Burly et Montsoreaux. *Cah. Lab. Montereau* 5: 73–84.
- Lennox, L. J., 1984. Lough Ennell: Laboratory studies on sediment phosphorus release under varying mixing, aerobic and anaerobic conditions. *Freshwat. Biol.* 14: 183–187.
- Liaw, W. K. & H. R. Mc Crimmon, 1977. Assessment of particulate organic matter in river water. *Int. Revue Ges. Hydrobiol.* 62 (4): 445–463.
- Lijklema, L., 1977. The role of iron in the exchange of phosphate between water and sediments. In H. L. Golterman (ed.), *Interactions between sediments and fresh water*. Dr. W. Junk B.V., The Hague: 313–317.
- Livingstone, D. A., 1963. Chemical composition of rivers and lakes. *Data of Geochemistry*. U.S. Geol. Survey Prof. Paper 440-G, 64 pp.
- Lorenzen, C. J., 1967. Determination of chlorophyll and phaeopigments: spectrophotometric equations. *Limnol. Oceanogr.* 12: 343–347.
- Martin, J. M. & M. Meybeck, 1979. Elemental mass-balance of material carried by world major rivers. *Marine Chemistry* 7: 173–206.
- Meybeck, M., 1982. Carbon, nitrogen, and phosphorus transport by world rivers. *Am. J. Sci.* 282: 401–450.
- Probst, J. L., 1985. Nitrogen and phosphorus exportation in the Garonne basin (France). *J. Hydrology* 76: 281–305.
- Relexans, J. C. & H. Etcheber, 1982. Cycles saisonniers de la matière organique particulaire à la limite amont de l'estuaire de la Gironde. *C.R. Acad. Sc. Paris*, t. 294, série II: 861–864.
- Richey, J. E., 1983. Interactions of C, N, P and S in river systems: a biogeochemical model. In B. Bolin & R. B. Cook (eds), *The major biogeochemical cycles and their interactions*. (SCOPE 21) Wiley, New-York: 365–383.
- Richey, J. E., J. T. Brock, R. J. Naiman, R. C. Wissmar & R. F. Stallard, 1980. Organic carbon: oxidation and transport by the Amazon river. *Science* 207: 1348–1351.
- Rippey, B., 1977. The behaviour of phosphorus and silicon in undisturbed cores of Lough Neagh sediments. In H. L. Golterman (ed.), *Interactions between sediments and fresh water*. Dr. W. Junk B.V., The Hague: 348–353.
- Ryding, S. O., 1988. Identification and quantification of nonpoint source pollution as a base for effective lake management. In J. Lauga, H. Décamps & M. M. Holland (eds.), *Land Use Impacts on Aquatic Ecosystems: The Use of Scientific Information*. MAB/UNESCO: 127–134.
- Ryding, S. O. & C. Forsberg, 1977. Sediments as a nutrient source in shallow polluted lakes. In H. L. Golterman (ed.), *Interactions between sediments and fresh water*. Dr. W. Junk B.V., The Hague: 227–234.
- Sparling, G. P., K. N. Whole & A. J. Ramsay, 1985. Quantifying the contribution from the soil microbial biomass to the extractable P levels of fresh and air-dried soils. *Aust. J. Soil Res.* 23: 613–621.
- Statistical analysis system, 1982. *SAS user's guide: statistics*. SAS Institute inc. Cary, North Carolina, 584 pp.