

Principle Relations Between Biomass and Production of Phytoplankton and Physicochemical Factors in Two Eutrophic Lakes of the Mediterranean Sea

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Abstract – Hydrological and biological studies on ecosystems of the lakes ‘étang de Berre’ and ‘étang de Vaïne’, the four rivers flowing into these lakes, and the Mediterranean Sea are carried out during the whole two-year period. The phytoplankton population of the lakes ‘étang de Berre’ and ‘étang de Vaïne’ is larger than that of the seawater or freshwater populations of four neighbouring rivers. This is due to the increasing nutrients such as phosphate, nitrate, and silicate flowing into the lakes from the four rivers. The superfluous phytoplanktons in the lakes flow into the Mediterranean Sea via the Caronte Canal. Phytoplanktons multiplied by phosphate of lake ‘étang de Berre’ can produce 10,160 tons of assimilated carbon per year, and those multiplied by nitrate produce 18,450 tons of assimilated carbon per year. According to Steeman Nielsen’s primary production estimation, phytoplanktons produce about 45,000 tons of carbon per year through assimilation in lake ‘étang de Berre’ and 10,000 tons of carbon per year in lake ‘étang de Vaïne’. The amount of carbon produced by phytoplanktons and the amount of phosphate, and nitrate are different according to the sea, river, and estuary.

Key words : eutrophic lake, phytoplankton, biomass, production, physicochemical factors

INTRODUCTION

The phytoplankton biomass of lake ‘étang de Berre’, and especially that of lake ‘étang de Vaïne’ is generally much more rich than the biomass of neighboring aquatic environments with really marine waters being the poorest (Fig. 1). The remarkable richness of nutritious salts in eutrophic lakes are the cause of abundant phytoplankton biomass (Fig. 2).

Indeed, nitrate, phosphate and silicate are brought in large quantities by fresh waters arriving at the lake

‘étang de Berre’. Part of these nutrients is not used and goes through lake ‘étang de Berre’ to reach the Caronte Canal and then the Mediterranean Sea. According to the contents observed at stations I and III that leave lake ‘étang de Berre’ in the direction of the Fos Gulf, and in the function of the volume of waters that leave this way (Kim 1988), we can roughly estimate the amount of nutritious salts lost by lake ‘étang de Berre’. The contents include elements coming directly from the fresh waters or being mineral salts coming from the regeneration of the eutrophic lakes.

As for phosphorus, a quantity of around 96.0 tons is then deducted from the 346.8 tons brought by fresh waters, allowing a positive result of 250.8 tons remain-

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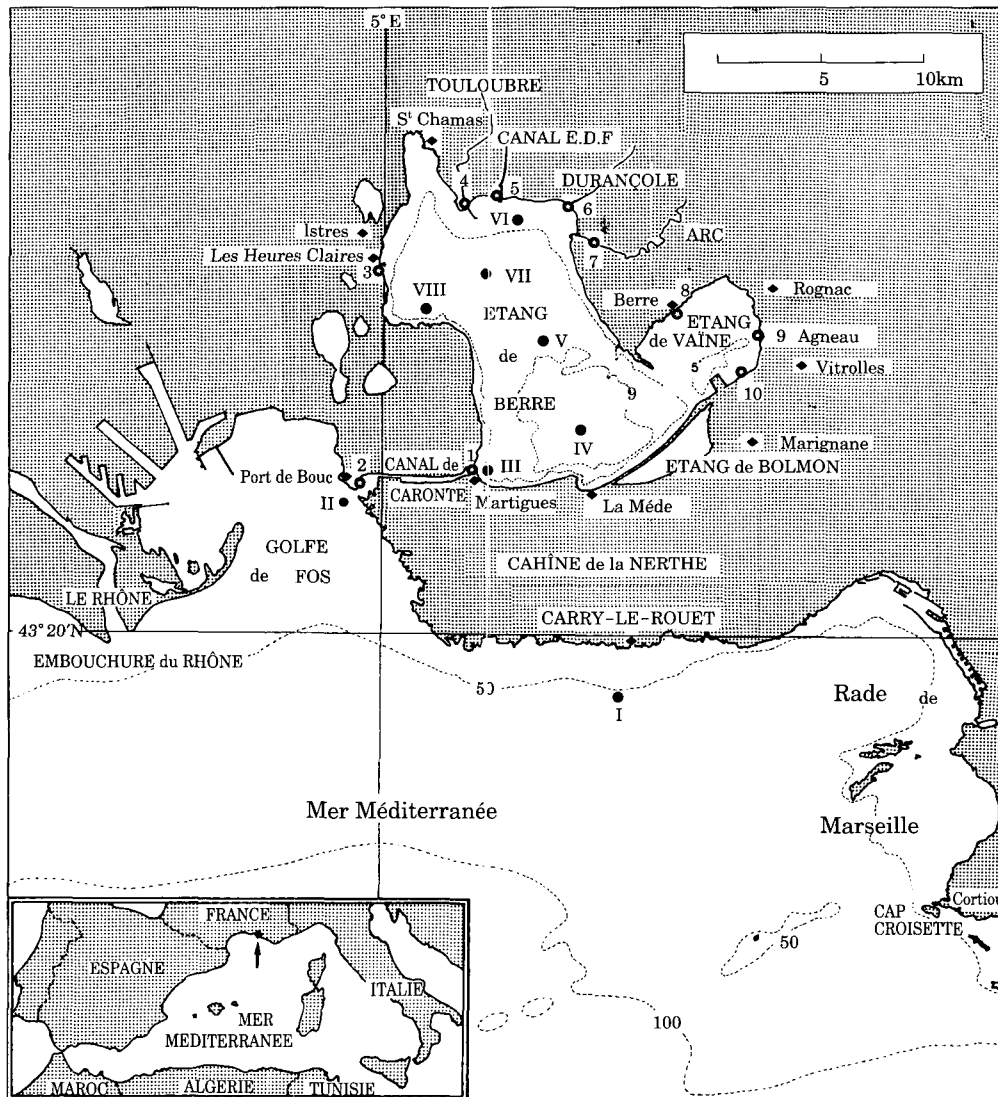


Fig. 1. Map of the two eutrophic lakes : 'étang de Berre' and 'étang de Vaine, four rivers and French Mediterranean Sea.

ing. Similarly, with regards to nitrogen and nitrate, 2713.0 tons will remain after subtracting 1830 tons from the 4543 tons brought by tributaries of lake 'étang de Berre'. Despite those reductions, the balance remains clearly positive and the fluvial intake enriches the local brackish environment a lot.

METHOD AND MATERIAL

Measurements of diverse hydrological and biological parameters were carried out in three different ecosystems. These ecosystems included the two brackish

lakes 'étang de Berre' and 'étang de Vaine' near Marseilles, France, which are diluted by four Rivers (Durance River, Arc River, Touloubre River, Durancole River) and the area of Carry-le-Rouet (Mediterranean Sea) about 25 km off the Rhône River outlet. Comparisons were made among marine waters, brackishwaters and freshwaters for two years (1976.12–1978.12).

On the other hand, biomass estimations using the Utermöhl's method, primary plagic production measurements and net production were also studied with previously reported values from diverse aquatic environments. A number of data (Kim 2002) and measurements methods were described in the series of the

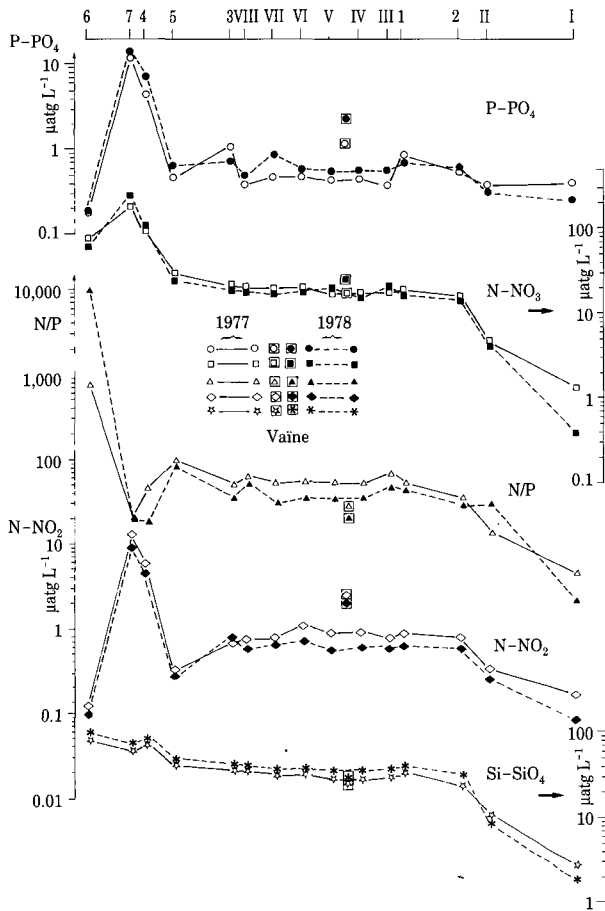


Fig. 2. Phosphate, nitrate, nitrate/phosphate ratio, nitrite and silicate in the eutrophic lake 'étang de Berre' (stations III-VIII and 3), four rivers (stations 4-7) and Mediterranean Sea (station I).

papers on the Lake, 'étang de Berre' (Kim and Travers 1977a, b; Travers and Kim 1977a, b, c)

RESULTS AND DISCUSSION

We (authors of the series of two brackish lake's papers) can refer to Fleming's classical equation (Fleming 1940) $C/N/P = 106/16/1$, or rather to the ratios better corresponding to phytoplankton alone: $108/15.5/1$, that correspond to weights of $40.5/6.8/1$. Then we can see that surpluses of yearly fluvial intakes would theoretically allow the synthesis of a amount of phytoplankton corresponding to 10,160 metric tons of C, and 18,450 metric tons for nitrates.

Despite the very rough character of those evaluations,

it seems that phosphate can become limiting much before nitrate, as were shown in the high values for the ratio N/P in lakes and fresh waters (Kim 1983). This difference between the roles of these two elements is increased by the fact that there are other sources of nitrogen like nitrite (intake of only 112 metric tons, by fresh water), and mainly ammoniacal or organic nitrogen.

As a result of previous paper (Kim 1983), a 1978 estimation using the Steeman Nielson method puts the production of C at 45,000 metric tons for the lake 'étang de Berre' (and probably around 55,000 metric tons for the two eutrophic lakes).

Therefore, fluvial intakes, though abundant, couldn't globally be enough, even if they would be all used in the eutrophic lakes for phytoplanktonic production. However, of course, in the waters and in the bottoms an important regeneration takes place as was shown by Minas (1974).

In addition, situations differ depending on the season (Kim and Travers 1983) and on the considered element. We can see that the waters nitrate content (Kim and Travers 1997a) varies a lot and can reach very low levels in summer with regeneration occurring slowly, through nitrite (Kim and Travers 1997b).

With regard to the phosphate (Travers and Kim 1997a), their limiting character appear less clearly in seasonal variations, though they are relatively less abundant, than nitrates. This is certainly because the release of organic phosphorus is faster than that of nitrogen. In addition, we have seen that the value of the ratio N/P varies considerably in the two eutrophic lakes during the year. The ratios vary from very high winter values to sometimes very low values in summer, though the ratio N/P varies a little in the fresh water intakes (Travers and Kim 1997b).

We notice also that, in the surface waters of 'étang de Berre', there is a positive correlation between the mineral phosphorus content and the fixation of ^{14}C ($r^2 = 0,179$, $r = 0,423$; Kim 1983). This is especially significant at station VII. On the other hand, no relation of this kind appears between chlorophyllous assimilation and nitrate contents.

It is possible to say, relying in particular on the ratio of N/P distribution, that nitric nitrogen was limiting for

phytoplanktonic development only during the second half of 1978, beginning in August, even it is probably relayed, at least partially, by other easily assimilated nitrogenous forms. On the other hand, phosphorus seemed to be often very limiting, at least until July 1978.

The water stream intakes are relatively less rich in phosphate than nitrate and often they must just compensate approximate losses due to exportation toward the sea of such allochthon phosphate, that on the spot regenerated phosphate and those leaving the Lakes under an organic form. A heavy limitation by the phosphorus appears clearly only in June 1977 and August 1978. However but it is certainly more general, especially during springtime.

It might also be interesting to continue to research to the presented data to see if two eutrophic lakes can be or are currently at the location of plankton-originated phosphorus or nitrogen accumulation. If we have recourse to examine the chlorophyll *a* measurement made at the 'étang de Berre' exit, and to the equivalencies used above, we notice the exit, as phytoplankton, of around 728 metric tons of nitrogen and 107 metric tons of phosphorus. If we compare them to the previous surpluses, calculated at the beginning of this paragraph, of 2713 and 251 metric tons, we can see that there can still remain each year, as an accumulation in the Lakes, around 2000 metric tons of nitrogen and around 144 metric tons of phosphorus.

Compared to Minas works (1974), conditions have noticeably changed and such an accumulation seems possible. It could also contribute to explaining the clear production superiority of 'étang de Vaïne' compared to 'étang de Berre'.

Of course, we must insist again on the fact that those calculations rely only on yearly evaluations and that a more detailed study would permit us to consider important seasonal variations.

The needs in silicon are more difficult to evaluate than the needs in nitrogen or phosphorus, considering the very different demands from the various phytoplanktonic algae classes for this element. Two eutrophic lakes are regularly enriched in silicon by heavy waters from tributaries of the two lakes (Travers and Kim 1997c). Nevertheless, in the summer of 1978 we notice

that in the brackish waters an important diminution of their concentration takes place due to the maintained algal synthesis demand while intakes from the Durance River dramatically decreased.

We can roughly estimate yearly fluvial intakes in silicon at 9345 metric tons though only 6284 leave 'étang de Berre' as a dissolved form. If the difference between those two values (more than 3000 metric tons) is too high to be equivalent to the 4340 metric tons of phytoplanktonic carbon that leave lake 'étang de Berre' (after a chlorophyll *a* measurement), it can be a certain accumulation of silicon in the two eutrophic lakes, the same for phosphorus and inorganic nitrogen. In fact, the possibility of such an accumulation depends closely on the taxonomic composition of the phytoplankton and can surely be rejected when diatoms represent an important part of the biomass.

Phytoplanktonic productions between Utermöhl method and ^{14}C method are not very different depending on 'étang de Berre', because physical and chemical conditions (temperature, transparence, light etc. and phosphate, nitrate etc.) for assimilation vary a little (Kim 1982). However, the phytoplankton biomass in 'étang de Vaïne' are twice to thrice more important than the ones of the lake 'étang de Berre'. However, lake 'étang de Vaïne' waters are noticeably richer than those of lake 'étang de Berre' are in nitrate, nitrite and especially in phosphate. Those specific richnesses may be linked to local specific intakes but also and certainly to the relative isolation of lake 'étang de Berre' that limits exchanges and especially exportation toward the Fos Gulf. In addition, its shallower depth often allows an active photosynthesis as far as the bottom, which improves the production and increases biomass per volume unit.

On the contrary, in lake 'étang de Berre', the waters closer to the bottom are not very productive, and almost all the photosynthetic assimilation is realized in the surface layer and the chlorophyll *a*, though present abundantly in the subsurface layer, lacks light to realize an active photosynthesis. However, it is exceptional when it does not occur at all (Kim 1983). Therefore, we can conclude that the estimation of compensation depth made here may be a little weak. The Vatova formula (Tolomio 1976): $Z_{1\%} = 3.3 Z_s$ would maybe be

more suitable than the Poole and Atkins formula (1929).

We have seen that phytoplankton productivity, as measured by the ratio $P/\text{chl } a$ or the ratio Pb/B is relatively low in the lakes, and anyway much inferior to the one of the waters from Carry-le-Rouet neighboring it (Ref. Detail data in the papers Kim 1979 and 1983). This seems to be mainly according to the tripton brought by the water streams.

Indeed, when the tripton is relatively little abundant in surface waters, we can usually observe a very significant negative correlation between transparency and phytoplankton cell volume ($r^2 = 0,620$, $r = -0,788$), whatever the method used to evaluate the phytoplankton. Then, we observe a very good correlation between transparency and chlorophyll a content at station I ($r^2 = 0,825$, $r = -0,923$). We would obtain equally a good correlation using ATP ($r^2 = 0,298$, $r = -0,545$) or results from the Utermöhl method at Carry-le-Rouet (Kim and Travers 1983).

On the contrary, there is nothing of the sort in lake 'étang de Berre'. There is no obvious correlation appears between transparency (Kim and Travers 1983) and phytoplankton (Kim and Travers 1984), though we have observed a fairly clear link between transparency and seston ($r^2 = 0,624$, $r = -0,790$; Kim and Travers, 1983). It is because in the two eutrophic lakes (and fresh waters) the phytoplankton represents a very small part of the seston: around 11 to 13% in lake 'étang de Berre' and 14 to 16% in lake 'étang de Vaïne' (after equivalencies in dry matter weight).

Consequently we can consider that the tripton brought by the Touloubre River, the Arc River and especially the Durance River blocks considerably the photosynthesis in two lakes and prevents the phytoplankton.

Two other causes can contribute to explain the relatively low productivity level of those brackish waters. They are the constant dilution of less important populations by fresh waters. And the constant phytoplankton losses on account of the brackish waters exportation toward the Fos Gulf and the sea. The entry of some seawater by the Caronte Canal reinforces this dilution phenomenon because this water is less populated than the lake's water.

However, we can not implicate a bad physiological state of the phytoplankton in brackish waters, because

their pheopigment level stays generally low, especially in lake 'étang de Vaïne'.

CONCLUSION

The yearly natural incident radiation cycle (Kim 1982a) seems to have actually a certain influence on the phytoplankton production and productivity cycle, but the biomass variations also surely depend on the browsing intensity by herbivores, which is a parameter about which we have little information.

Temperature (Kim 1982b) can certainly play an important role in the phytoplankton development in the sea, especially through its dominant role in density. However, its influence seems much more limited in brackish waters, where actually density is much more controlled by salinity (Kim 1988).

Other environment parameters are more influenced by the phytoplankton. It is especially true for those linked with the gaseous metabolism of those organisms. For instance, the studied brackish waters have a remarkable richness of oxygen, compared to the other environments which is certainly linked to the intense photosynthetic activity that takes place there. On the contrary, the poverty in carbonic anhydrides, a result of the high demand from phototropic organisms, is certainly the cause of the relatively high pH of these environments compared to neighboring ones (Travers and Kim 1990). In the same way, photosynthetic activity seems to have consequences on the alkalinity value.

Of course, the chemical and bacterial degradation of the organic matter is responsible for the opposite evolution of these parameters, with variable intensity, but seeming especially important in lake, 'étang de Vaïne'.

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