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# Limnology, phytoplankton dynamics and recolonization of phytoplankton in relation to flow regime and fish removal biomanipulation (whole-lake emptying, 1995) of the Pont-de-Salars reservoir (southwest, France) from 1993 to 1996

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## I. Introduction

The limnology of Pont-de-Salars reservoir (Aveyron, France) had not been investigated previously, apart from a TP model study. Moreover, this reservoir is the uppermost part of all the regional reservoirs and thus its water quality may influence that of reservoirs downstream. Therefore, it is the whole drainage basin, not just the body of water, which must be considered as the minimum ecosystem unit when it comes to assessing mans impacts.

Pont-de-Salars reservoir is the uppermost part of a series of reservoirs in the Aveyron - Tarn complex in southern France. The numerous studies carried out on Lake Pareloup, a downstream reservoir just after Lake Bage, have suggested that the Pont-de-Salars reservoir is the most important for the successful management of the series of reservoirs.
Since its construction in 1952, the reservoir has been completely emptied twice ; in 1972 without monitoring and between August 21 and September 1, 1995. During the second operation, fish (over 30 tons, mainly roach (21 tons) and pikeperch (4 tons)) were taken out and the subsequent refilling with water was carried out without reintroducing the fish.

Phytoplankton makes up a portion of the autotrophic component of the aquatic food web in lakes or reservoirs. The phytoplankton provides an energy link between the physical

environment (solar energy) and the animal and microbial consumers. They are also a nutrient link between the chemical environment and other levels of the food web. Being dependent upon absorption of dissolved nutrients for growth, the phytoplankton build their biomass directly from the chemicals from the environment and strongly influence the structure of the chemical environment by the absorption of nutrients and by the release of various inorganic and organic substances. It is evident that much can be learned about the ecology of a lake or reservoir through studies of the structure and behavior of the phytoplankton community.

Depending on watershed, inflow characteristics and flushing rates (outflows), each reservoir is unique. Reservoir plankton communities may offer excellent opportunities for the investigation of ecological responses to episodic environmental disturbances and ecosystem resilience.

Thus we have a good opportunity to study :

- General limnology in relation to the role of its main inflow (the Viaur river) and of usual outflow operations as well as of the emptying
- Spatio-temporal phytoplankton dynamics
- Recolonization of planktonic diatom from the sediment
- The impact of biomanipulation in a deep and generally stratified reservoir in order to summarize a hypothetical model for the function and structure of the reservoir.

## II. Results and discussion

The reservoir is of the canyon type, horizontally long and dendritic, sheltering the water surface from the wind. It is a warm, monomictic lake.

The main inflow, the Viaur river exerts the major influence among the various watershed inflows. The seasonality of the alkalinity, conductivity, and nitrate nitrogen in the reservoir seemed to follow that of the Viaur river.

Therefore, it is necessary to improve the water quality of the Pont-de-Salars watershed (not just the reservoir) in order to reach better water quality downstream. Moreover the Pont-de-Salars reservoir has never shown nutrient deficiencies probably due to high nutrient loadings of its inflow and surrounding land use patterns (i.e. agriculture, cattle farming). Thus, in the Pont-de-Salars reservoir, nutrient limitation should not be critical due to high external and internal P and N loadings (highly accumulated at lower depths). It does, however, became

important following the flow operations including biomanipulation which always results in a highly disturbed system.

We observed great fluctuations in interannual and annual phytoplankton biomass (biomass in fresh weight and chlorophyll *a*) and abundance from 1993 to 1996 as in other lakes. Moreover, a fortuitous biomanipulation (total removal of fish), involving whole-lake emptying, was carried out in 1995.

These inter- and intra-annual changes in phytoplankton biomass (biomass in fresh weight and chlorophyll *a*) and abundance were accompanied by compositional changes in phytoplankton groups and species, as shown by descriptive methods, cluster analysis, and Canonical correspondence analysis (CCA). It was difficult to identify a mean seasonality, a typical year for the typical seasonal succession, and a characteristic species in the season.
As for major groups based on their relative abundance and biomass, there were Chlorophyta and Diatoms before and after the biomanipulation. The peaks of phytoplankton biomass and abundance occurred in early spring and mid- to late summer before the biomanipulation as in other lakes. The increase in the proportions of phytoflagellates (of the total phytoplankton biomass particularly) was observed after the biomanipulation and it was mainly due to the contributions of Chrysophyta and Cryptophyta.

CCA indicated that the phytoplankton assemblages in the euphotic zone were strongly correlated with water temperature to generate a separation between isothermal and stratification periods as well as nitrate nitrogen ($NO_3$-N) and silica (Si) concentrations of the reservoir, and the inflow over the study period. CCA also indicated that Secchi disk depth (SD) was the mostly influenced factor by a biomanipulation in the epilimnion during summer stratification accompanied by a spectacular changes in the phytoplankton assemblages

Diatom assemblages preserved in lake sediments can directly reflect the diatom flora in the water column. Diatom assemblages of the top layers in the sediments were similar to (sub)dominant diatoms in the euphotic layer before the biomanipulation period. Thus the two assemblages between sediments and water columns complement the annual phytoplankton records and also provide additional information describing the temporal responses of them

(diatom assemblages) to disturbances like eutrophication (vertical variability) and biomanipulatin (recolonization in the euphotic layer).

We can set up a model to depict the function of phytoplankton dynamics in relation to environmental factors. The Pont-de-Salars reservoir shows a continuously disturbed system with mostly *r*-strategists in phytoplankton due to hydrological events or flow regime : inflow, outflow (surface discharges, subsurface pumping, outlet of inflow and whole-lake emptying), and their synthesized functions (water level fluctuations and a short water retention time). After the biomanipulation, the water level varied less than before the biomanipulation.

In spite of interannual variations from 1993 to 1995 i.e. before the biomanipulation, the ecosystem of the reservoir may be considered as an unchanged system (A-A′) and this same system can be altered (B) after the biomanipulation. A complete removal of fish using whole-lake emptying resulted in a decrease in phytoplankton production (abundance, biomass and chlorophyll *a*) and an increase in water transparency i.e. water quality improvement. The reduction of phytoplankton production has also altered periods of annual peaks (i.e. highest summer peaks before the biomanipulation and vernal, autumnal peaks after the biomanipulation) as well as phytoplankton species composition.

In this system, hydrological characteristics also play an important role in nutrient dynamics. We observed a continuous decrease in ammonia and TP levels contrary to the increase in SS concentrations in the inflow from 1993 to 1996. During summer stratification, the inflow entered the reservoir as an interflow and so it could not possibly supply the upper layers with the nutrients (i.e. epilimnion and upper metalimnion). After the biomanipulation, TP and SS values near the bottom of the reservoir were higher than those of the inflow, and thus it indicating that sedimentation and resuspension occurred at a higher rate.

In sum, a fortuitous biomanipulation (total removal of fish) plays the key role ( top-down ) and results in the enhancement of water quality in this reservoir. This maybe accompanied by ammonia and TP reductions ( bottom-up ) : a decrease in phytoplankton production and an increase in early summer water clarity during the first year after the biomanipulation in spite of the rarely recommended morphometry of a deep, large, and stratified lake and finally perhaps due to an increase in grazing pressures on phytoplankton.