Changes of Colony Sizes of *Asterionella formosa* Hass. in the Sorpe Reservoir

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Abstract

Asterionella formosa can be observed during the first half of the year in both basins of the Sorpe reservoir. The number of cells per colony vary with time. This variation is best seen in the pre basin, where the 8-celled colonies are getting more numerous, while number of the 4-celled colonies is sinking. The influence of Si-content, temperature and light intensty on this phenomenon is discussed.

Introduction

In an ecosystem exists a certain number of niches, so organisms have to compete on several factors to be able to settle in an given niche. To maintain the necessary fitness they have to react on changing environmental conditions. The influencing factors that come into question for a planktonic alga in a standing water body are mainly the supply of nutrients, light regime, temperature, or its use as a diet for the next organism in the food chain. If an organism or a population is observed that undergoes changes in size, shape, colour or whatever attribute, the suspicion lies on the hand that these changes are reactions on changing environmental conditions.

Asterionella formosa forms part of the spring plankton of the two basins of the Sorpe dam. It appears at the beginning of the year and vanishes around may. In april it is the dominating form of the net phytoplankton. It is mainly known as a pennate diatom, organized in stellate colonies with usually eight cells. But evidence shows that *A. formosa* can be found with varying colony sizes and various shapes. It exists with two up to 32 or even more cells per colony. It is also found as unicellular alga. Colony shapes vary between stars (stellate), parts of stars (mainly halves), or *Tabellaria*-like chains. The differences in colony size were brought into connection with nutrient limitation (e.g. Lund 1963, Tilman et al. 1976) or temperature (Hayakawa et al. 1994), while hydrodynamic conditions are said to count for variations both in colony shape and size (Bertrand et al. 2003).

Sampling sites

The Sorpe reservoir forms part of the dams which supply the Ruhr industrial region with water (fig. 1). The reservoir lies in the mountains of the Sauerland (North-Rhine Westphalia, Germany) in a catchment area of about 100 km^2. It consists, similar to the remaining dams of the Ruhr basin, of a pre- and a main basin.

Pre basin

The purpose of the pre basin is the reduction of nutrients to keep the main basin and the subsequent waters of the river Ruhr in nutrient poor state. It measures about 1 km both in length and width and has a maximum depth of 9 m. It is separated by a barrier from the main basin. At maximum level the barrier lies about 1 m under the surface, so that the uppermost layer is common to both basins in the time, when the reservoir is filled to maximum. The pre basin receives nutrient-rich effluents from a biological sewage treatment plant and from a stream, running through agricultural used land. The nutrient status of the pre basin is highly eutrophicated. Sampling usually was done from the bridge over the barrier between the two water bodies (① fig. 2).

Main basin

The waterbody of the main basin forms a slightly curved bow of 6.2 km length and 700 m width (measured at the north end), orientated from south to north-east. Its surface spreads over 3.38 km^2, the maximum depth is 57 m, while the mean depth measures 21 m. The total volume is 70.8×10^6 m^3. The theoretical filling time is 1.53 years. It receives the waters of the pre basin and the nutrient poor waters of the Settmecke channel. The nutrient status is oligo- to mesotrophic (LAWA 1990). Sampling usually took place in the vicinity of the deepest point (⑥ fig. 2) or, if weather conditions did not allow to take samples from the boat, at the jetty of the station ⑦. The depth at the jetty is about 2 m. For examining a longitudinal section of the Sorpe reservoir, additional sampling sites (②–⑤) were used.

Methods

Sampling was done in irregular intervals from March 2002 on with a 40 μm plankton net. We usually took vertically mixed samples between 7 and 0 m in the pre basin and between 10 and 0 m in the main basin. At the jetty sampling was done horizontally in a depth of 0.5 to 1 m. Two subsamples were preserved in Lugol's solution (according to Schwoerbel 1994) resp. 2 % formaldehyde. In elder samples the colonies disintegrated into single cells due to the damage of the mucous joints by Lugol's (Müller 2005), so we used primarily 2004 samples. For counting a Lomo Biolam microscope was used, the 9× objective usually was sufficient. We tried to count at least $800 \cdots 1000$ cells per sample, but when *Asterionella* was scarce, it was not always possible to reach that number. For silicate analysis the visocolor tests of Macherey-Nagel were used. Si was measured as SiO_2 with the Macherey-Nagel PF-10 photometer. Though

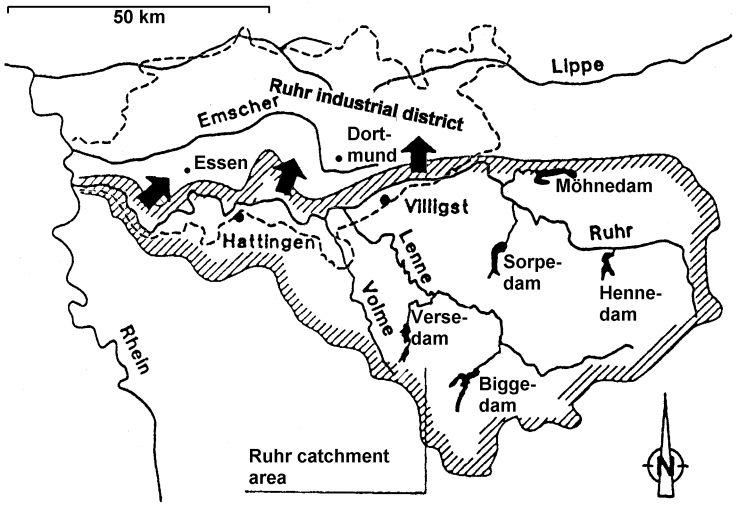

Figure 1: Reservoirs in the Ruhr catchment area (from RISSLER 1997, modified)

silicate was measured in several depth, only the surface values are considered here. For temperature measurement a WTW probe Oxi 325 or 330 with a 100 m cable was used. Secchi measurements were made with a white painted square metal disc, which measures 25 × 25 cm.

Results

In january 2004 *Asterionella formosa* began to develop in the Sorpe reservoir. In february we had the opportunity to undertake a orientating longitudinal survey of the main basin of the reservoir taking samples from the shoreside stations. Though *Asterionella* has not yet developed higher numbers (*Melosira* was the main alga), there were some *Asterionella*-colonies in the samples which showed a certain dependence of colony size in relation to distance from the reservoir's origin (fig. 3).

The *Asterionella*-colonies of the south end of the main basin in february consisted mainly of 4 cells (47 % of total cell number), some were made of 8 cells (31 %) ond only 11 % of the cells were aggregated in a 16-cell colony. These relations change when we went further upstream in the reservoir. At the jetty of the sailing club CCSS (fig. 2) a higher number of 11-celled colonies was found, but the number of both smaller or larger colonies were very small. At the north end a higher number of 8-celled colonies appeared (50 % of total cell number) and even 16-celled colonies were encountered (22.8 %). If you give the results from the sailing club station ⑤ less attention (due to the very small numbers of *Asterionella*-colonies found there (with 1 or 2 per colony type, and 11 for the 11-celled type this should be allowed), it gives a hint, that the colony sizes may become larger in the course of the water in the reservoir.

This was the ignition spark to further investigations to find if this regularity is reproducible. They consisted of a time course survey of *Asterionella* both in

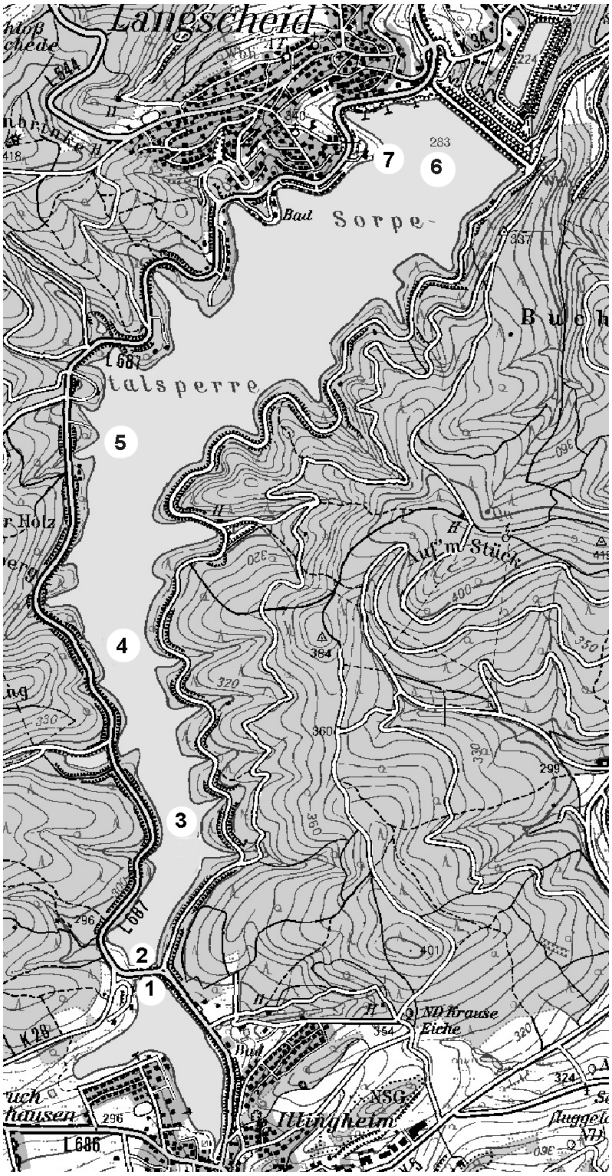

Figure 2: Sorpe reservoir with sampling stations (① – pre basin, ② – north side of south dam of main basin, ③ – opposite Settmecke channel, ④ – RV buoy at the centre of the main basin, ⑤ – sailing club CCSS, ⑥ – RV buoy at the deepest point of the main basin, ⑦ – jetty at YH)

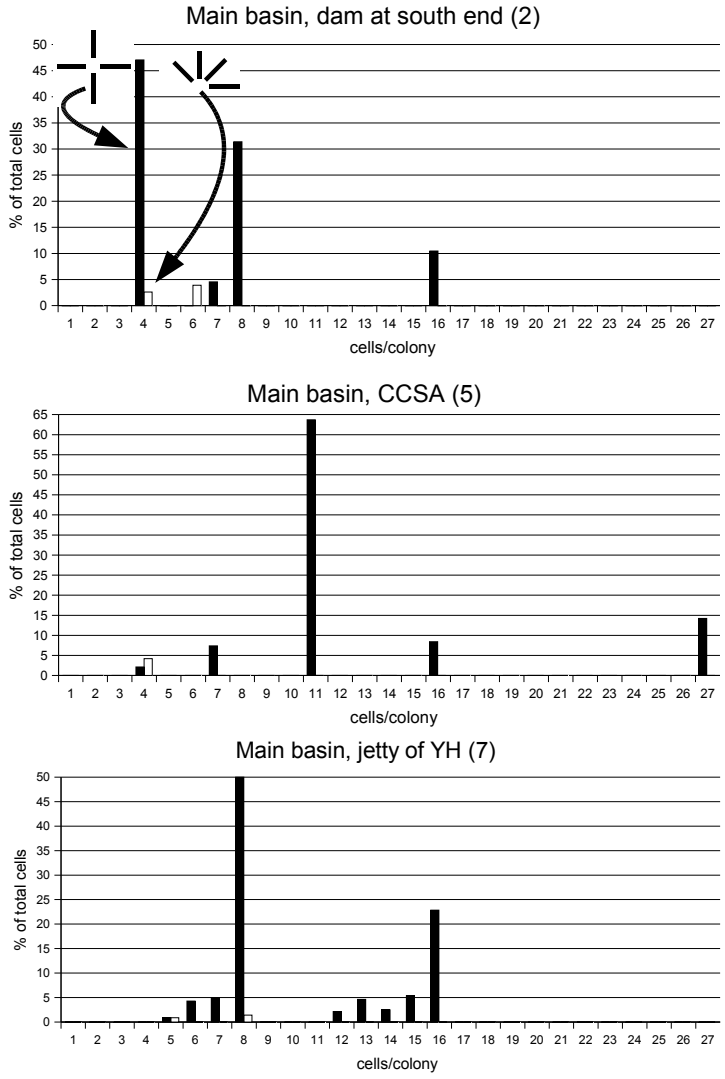

Figure 3: Orientating survey on 17. feb. 2004 (black: stellate forms, white: damaged forms (halves of stars)

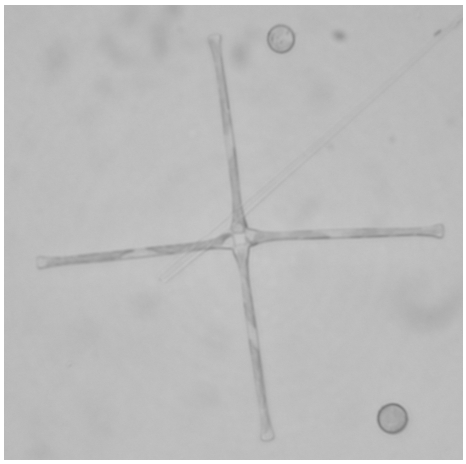

Figure 4: *Asterionella formosa*, four celled colony

pre and main basin plus a second longitudinal survey.

Pre basin

More than 90 % of the cells forming stellate colonies in the sample collected 13. january 2004 at sampling station ① consisted of four cells forming a regular cross (fig. 4).

The relative number of 4-celled colonies grew smaller until summer, when 8-celled colonies far outnumbered any colonies of different cell numbers: on may, 26th, around the end of the *Asterionella* period (and with very few *Asterionella* in the sample), only 4.6 % of the cells belonged to 4-celled, but 82.6 % to 8-celled colonies. Also a 14-celled colony appeared at that date, but the number of cells of this forms only contributed 13 % of the total cell number. A colony of 16 or more cells never was observed in the pre basin (only regular stellate colonies werde regarded, fig. 5).

Asterionella had its maximum in april, and after may it vanished and could be detected only in very small numbers.

Besides stellate colonies also colonies of different shape were observed which looked as parts of stellate forms. The most abundant form of these colonies consisted of 4 cells with the same angle between the cells as in 8-celled colonies, so they looked like 8-celled colonies split in two halves.

Si concentration in the surface layer grew smaller in the course of the time. Starting with $5 \cdots 6$ mg/L in february it decreased to 0.5 mg/L in may (measured as SiO_2, fig. 6).

Main basin

In the main basin (samples from stations ⑥ or ⑦) the inclining of colony size during time can not be watched. The in eight cells organized forms do outnumber the cells in 4-celled colonies about tenfold or more, even already in january. Larger colonies (10 cells per colony or more) can also be found, but in smaller numbers than the 8-celled colonies. The largest colony observed in this study

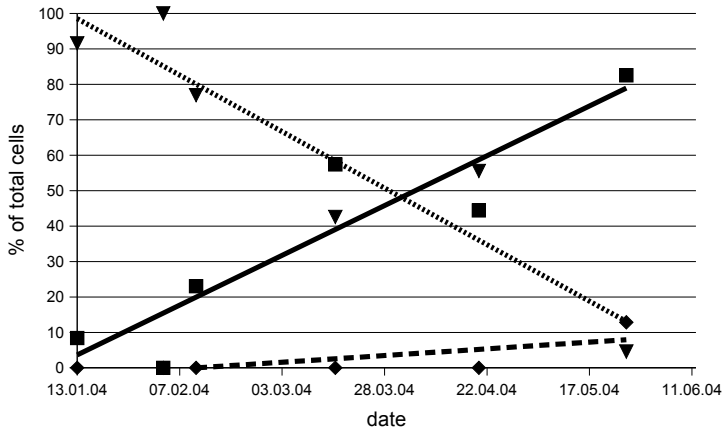

Figure 5: Distribution of colony sizes of *Asterionella formosa* from january until may 2004 in the pre basin. Only stellate forms are counted. Graph shows regression curves: dotted (▼): 2 to 6 cells (mainly 4), solid (■): 7 to 10 cells (mainly 8), dashed (◇): 14 cells.

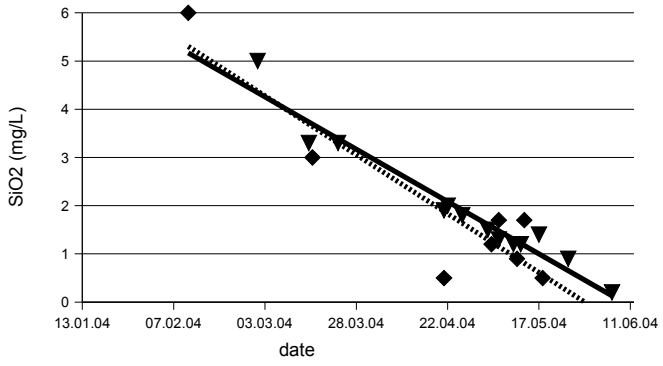

Figure 6: Si concentration in the pre and main basin (near surface), measured as SiO_2. Graph shows regression curves: dotted (◇): pre basin, solid (▼): main basin

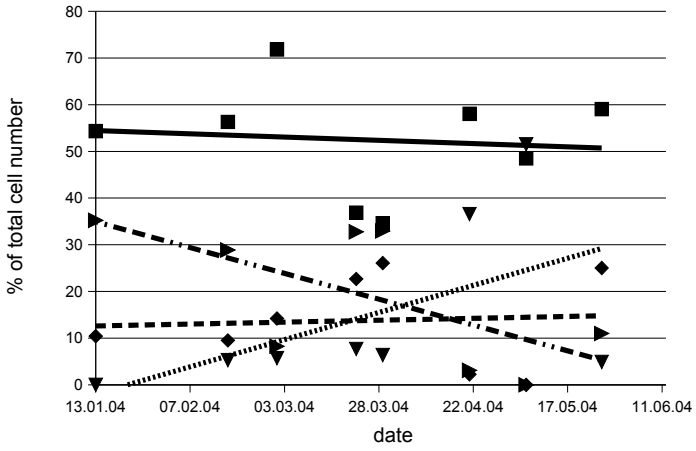

Figure 7: Distribution of colony sizes of *Asterionella formosa* from january until may 2004 in the main basin. Only stellate forms are counted. Graph shows regression curves: dotted (▼): 2 to 6 cells (mainly 4), solid (■): 7 to 10 cells (mainly 8), dashed (◇): 11 to 14 cells, dashed/dotted (►): more than 14 cells.

consisted of 28 cells, but only observed twice on 29. march, while colonies with 16 to 18 cells were found quite regularly (fig. 7). Generally speaking, colonysizes in the main basin were larger than in the pre basin.

Si concentrations in the main basin started with 5 mg/L at the beginning of march and fell unto 0.2 mg/L in june. Linear regression curves show that the consumption of Si in the pre basin is a little faster than in the main basin (fig. 6). This is understandable because of the larger primary production in the eutrophic pre basin.

The second longitudinal examination, which took place on 21. april 2004, showed the same result (fig. 8): cells belongig to 4-celled colonies in the pre basin (station ①) were about 61.7 % of the regular stellate forms, while those from 8-celled colonies were only 11 %. But at the first part of the main basin (near Settmecke, station ③), both forms nearly equalled: 34 % of the cells were organized as 4-celled, and 37.7 % as 8-celled colonies. Further on in the main basin (centre, station ④) 36.8 % were in 4-celled, and 36.2 % in 8-celled colonies. At the end of the main reservoir (deepest point, station ⑥) the relation between these two form benefitted the 8-celled colonies: only 24.8 % belonged to the 4-celled group, whereas 43 % formed 8-celled colonies. The number of greater colonies was 0 at the pre basin and little, but not significantly larger in the main basin, especially at the deepest point. Obviously was, that at this date a very large amount of the cells in either basin belonged to the damaged forms (which are not included in the above numbers): 38.2 to 43 % of the total cell number formed parts of stars, mostly 4-celled halves.

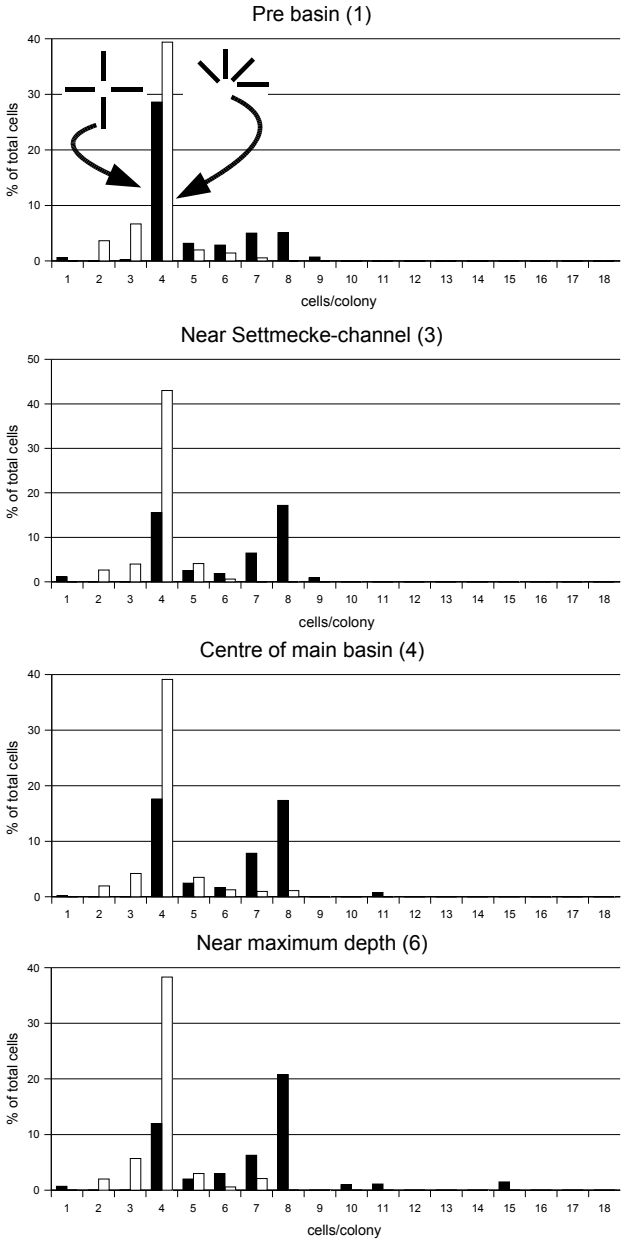

Figure 8: Orientating survey on 21. april 2004 (black: stellate forms, white: damaged forms (halves of stars)

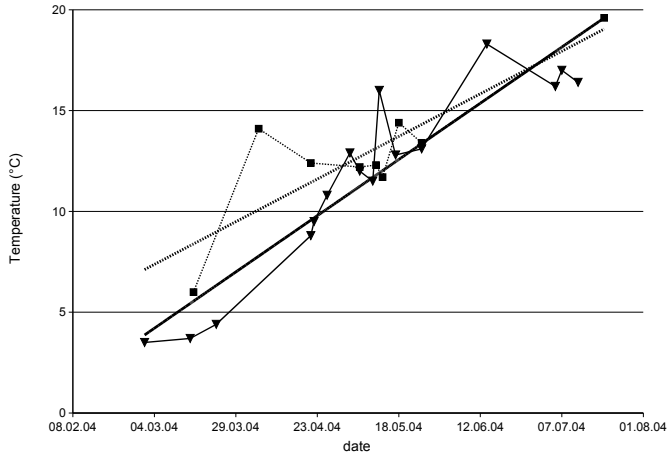

Figure 9: Temperatures in the pre and main basin (near surface) with regression curves: dotted (■): pre basin, solid (▼): main basin

Temperatures and Secchi depths

Temperatures in both basin were measured at irregular intervalls. The surface measurements are shown in fig. 9. The spring turnover in the pre basin took place earlier (!!!date!!!) than in the main basin (15. march 2004) because of the lesser volume and depth of the pre basin. The short time effects of changing air temperatures can be found in the irregular shape of the graphs.

Secchi measurements were made from march on (fig. 10).

Discussion

Tilman's experimental study (Tilman et al. 1976) shows, that the colony size in phosphate limited media decreases, and increases with silica limitation. Their experimental results can be confirmed partly in our study of naturally occuring *A. formosa*: the phosphate limitation in the main basin is severe, but in contrast to Tilman's findings we don't observe smaller colonies than in the pre basin with higher TP values. But on the other hand, in both basin we have a continuing sinking Si content from january until summer, an in the pre basin we indeed find smaller colonies in the early month of the year with high Si content and larger ones later, when the Si concentrations are lower. But this concept is not observable in the main basin, though the development of the Si content is comparable (fig. 6).

Hayakawa and Kudoh (1994) found that nutrient status alone can not count for the differences in colony size and shape. They point out that the temperature of the water is an important factor in influencing the colony size: In warmer water the colonies are larger than at lower temperatures. This is

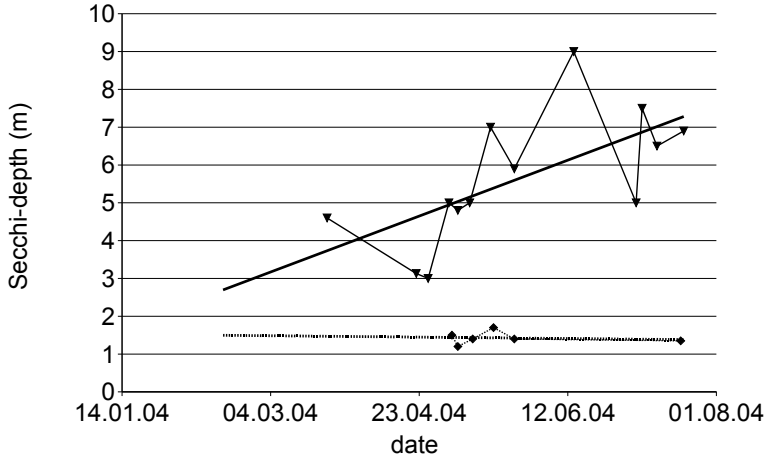

Figure 10: Secchi measurements with regression curves in the pre basin (dotted, ⋄) and main basin (solid, ▼)

understandable: the viscosity of the watewr sinks with rising temperature. So, to maintain a low sinking velocity colonies must get larger: Jaworski et al. (1988) show, that 8-celled stellate colonies have, more or less independent from the size of the cells, the lowest sinking values. But our results in the main basin cannot confirm Hayakawa's and Kudoh's observations: The linear regression curves of the data show, that the fraction of the small colonies ($\pm$ 4 cells) seems to grow during the first month of the year, when the water is getting warmer, and the number of large colonies ($\pm$ 14 cells) sinks, while the fraction of colonies of a intermediate size ($\pm$ 8 $\cdots$ 12 cells) keeps its number (Fig. 7). But the data itself form a very irregular scheme, so that the reliability of the regression graphs is not very great. The pre basin, on the other hand, indeed seems to correspond with Hayakawa and Kudoh: the number of small colonies ($\pm$ 4 cells) sinks with rising temperatures, while the larger colonies ($\pm$ 8 cells) are getting more numerous (fig. 5).

Bertrand et al. (2003) analyzed the *Asterionella*-populations of the Durance and Verdon system in southern France and found differences between more or less turbulent parts of the rivers in respect to colony size and -shape: with low turbulence they found about 40 % 8-celled colonies and 40 % 4 or less-celled colonies, but with medium turbulence the numbers changed to 25 % and 55 %, resp. Betrand and her co-workers proposed an explanation, which distinguishes between small colonies of "colonisateurs" and larger "competiteurs" (strong in colonization and strong in competition). The different hydrodynamic conditions determine which type fits better in the environment. With low turbulence the larger colonies have more advantages, because their sinking velocity is lower. With high turbulence the advantages are on the side of smaller colonies, because they form more daughter colonies in a given time (Jaworski et al. 1988).

It is not possible to transfer BERTRAND's concept to the Sorpe reservoir, because the velocity of flow in both basins is small compared even to the more or less standing parts of the Durance or Verdon. So turbulence is obviously not the reason for the observations in the Sorpe basins. But the environmental pressure on the colony size must be present, otherwise the observed changes would not have taken place. Until now we did not consider another important factor: the light regime. Unfortunately we could not measure the photosynthetic active radiation under the surface, but we took some Secchi depths. The highly eutrophic status of the pre basin is reflected in the low Secchi values of about 1 m. TILZER's (1988) empirical formula to calculate the euphotic depth from the Secchi depth ($Z_{eu} \approx 5 \times \sqrt{Z_s}$) is not applicable, but oxygen measurements (ÖKO-SORPE 2004) let one assume an euphotic depth of about 4 m. The chance to sink into a dark, mortal depth is much greater for a 4-celled colony than for a 8-celled colony because of its higher sinking velocity. But in the beginning of the year BERTRAND's concept of "colonisateurs" makes sense: smaller colonies mean faster reproduction, so that after the low population status of the winter the colonization of the water body by *Asterionella* is assured.

This consideration is not applicable in the main basin, where Secchi-depths between 3 and 9 m are measured. Here TILZER's formula is congruent to oxygen measurements. We have euphotic depths between 7 and 15 m, so that sinking is a smaller problem for *Asterionella*. The pressure to avoid the dark zones is actually getting smaller during the spring, because Secchi depths are getting larger and so the euphotic zone is growing until june.

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