

Improving the Understanding of Cyanobacterial Bloom Formation Mechanisms in Lake Biwa*

Antonio Quesada^{1,2}, Jean-Jacques Frenette^{3,4},

Kazuhide Hayakawa¹ and Michio Kumagai¹

¹Lake Biwa Research Institute, Otsu, 520 Shiga, Japan

²Dpt. Biologia. Universidad Autonoma de Madrid. 28049 Madrid, Spain

³Center for Ecological Research. Kyoto University. Shimosakamoto, Otsu, 520-0105 Shiga. Japan

⁴Lake Biwa Museum. Kusatsu, Oroshimo, 525-0001 Shiga, Japan

Abstract: Blooms of cyanobacteria are responsible for many problems in freshwater ecosystems. The massive growth of these microorganisms may limit the utilization of freshwater for human requirements since, apart from other problems, the production of toxic substances has been found to occur frequently during blooming periods. Ecologically, cyanobacterial blooms can modify dramatically the ecosystem through their low edibility within the food web and the huge primary production. Thus, saprobic processes are stimulated and the characteristics related to anaerobic conditions are also more extreme.

Cyanobacterial blooms are many times explained as the consequence of the eutrophication of waterbodies. However, factors promoting bloom formation and ecological succession of cyanobacteria are not well understood yet.

Keywords: Cyanobacterial bloom, Lake Biwa

Lake Biwa is the largest lake in Japan and one of the oldest lakes in the world (4 million years old). Since the last 20 years, cyanobacterial blooms have been a recurrent event in the shallow South basin of Lake Biwa. More recently, similar growth of cyanobacteria has been found also in the deep North basin.

In this paper we document the dynamics of a *Microcystis* bloom during diel (24 h) cycles, in order to identify the ecophysiological behaviour of the bloom and to improve our understanding of the bloom-forming mechanisms.

1. Methods

Experiments were conducted in summer 1996 (from July to September) in 100 m² enclosures deployed in Akanoi Bay within the South Basin of Lake Biwa. At that time a *Microcystis* bloom

* Received 1997-02-25; accepted 1998-03-27.

appeared and its evolution was followed in 24 h cycles. Sampling was conducted every 2-3 h at two depths: 20 cm and 1.2 m of the watercolumn (the watercolumn was 1.5 m deep). At each sampling period phytoplankton abundance was measured as chlorophyll *a* (Chl *a*) content. Particulate organic C (POC) in the sestonic fraction was measured by filtering samples through GFF filters and using elemental analyzer.

Physiological variables were also measured within the watercolumn: respiration ratio using the oxygen consumption technique by mean of the Winkler method; photosynthetic rate as C uptake using ^{13}C -bicarbonate and mass spectrometer; potential photoinhibition was measured using the DCMU induced fluorescence technique. This technique is based on the variable fluorescence intensity produced under different physiological states (Fb), and compared to the maximum fluorescence obtained with the inhibitor DCMU (Fa). Thus, high values of the difference Fa-Fb indicate low potential photoinhibition, and low values indicate high potential photoinhibition.

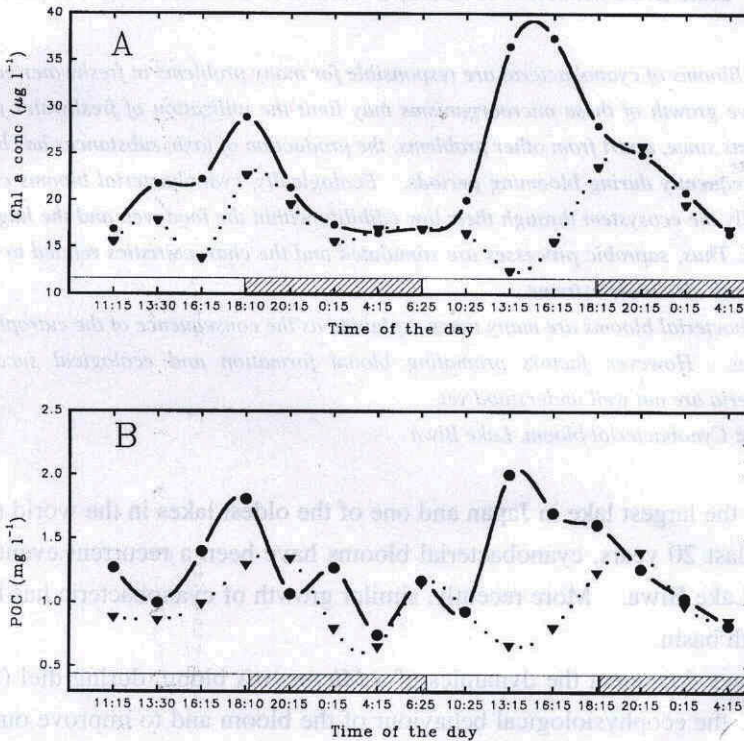


Fig. 1 Biomass variation during the day at surface (20 cm deep), solid line, and bottom (1.2 m), dotted line. A) Chlorophyll *a* content and B) Particulate organic carbon (POC). Clear boxes represent day-time, and shaded boxes represent night-time.

2. Results and Discussion

Chl *a* concentration was maximum at surface during midday and minimum after midnight.

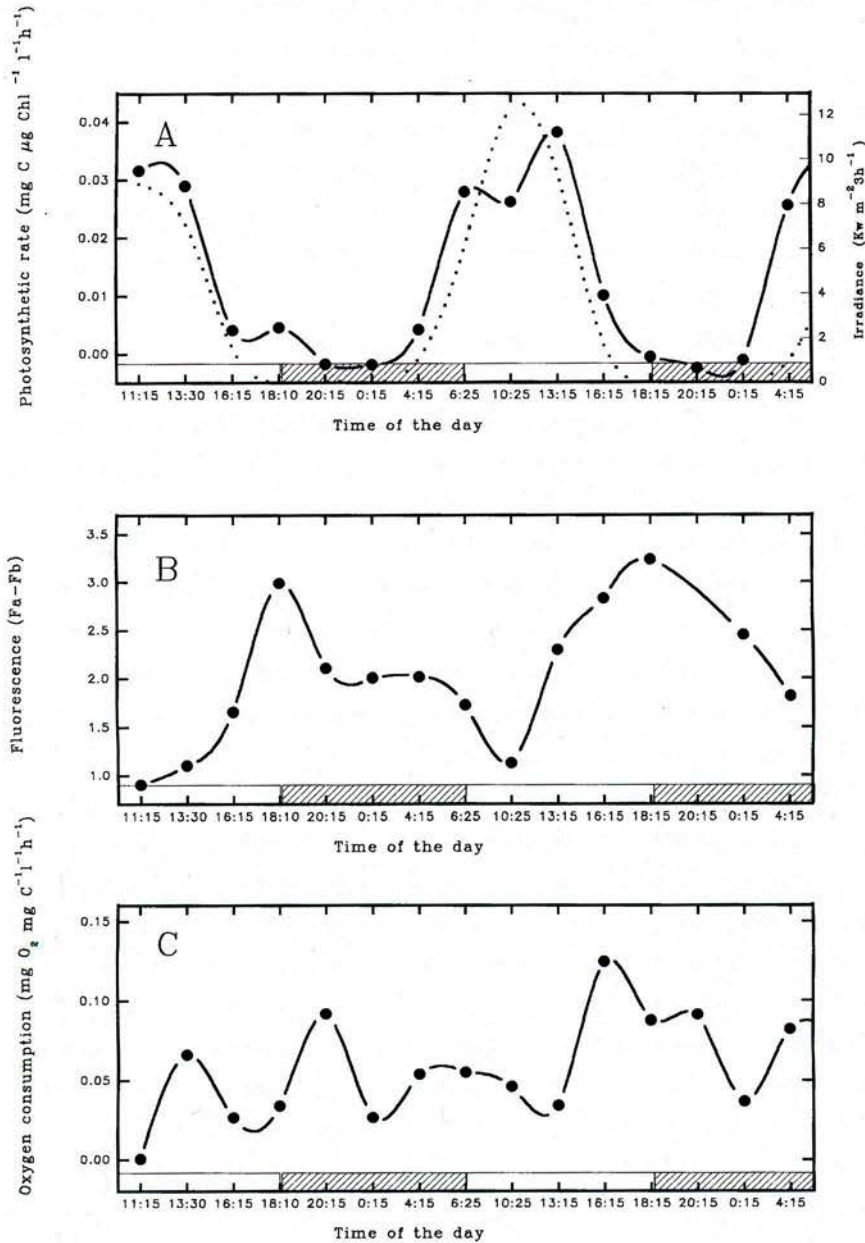


Fig. 2 Irradiance and physiological activities variation of surface biomass along the day.

- A) Variation in irradiance (integrated in the 3 h incubation), dotted line, and in photosynthetic activity as C uptake, solid line.
- B) Difference in fluorescence (relative units) after the addition of the inhibitor DCMU and before. This value is used as an estimation of the potential photoinhibition, (i.e. low values indicate high potential photoinhibition and high values indicate low potential photoinhibition).
- C) Variation in oxygen consumption.

However, trends at the bottom were quite different, with minimum and maximum values during the day and at early evening respectively and low values after midnight (Fig. 1 A). Particulate organic C (POC) showed similar pattern than Chl *a* content (Fig. 1B), suggesting changes in the phytoplankton cell number rather than in Chl *a* concentration per cell.

These results demonstrated that cells changed position along the day. Early after the sunrise cells started to float, increasing biomass at the surface with a loss at the bottom. This trend went on, reaching the maximum flotation in the afternoon. At early evening cells sank and could reach the sediment surface in the night.

Surface photosynthetic activity measured as C uptake followed a diurnal pattern directly influenced by the irradiance variation (Fig. 2A). Photosynthesis rapidly increased after the sunrise, followed by a slight decrease during the maximum morning irradiance. Maximum activity, expressed in Chl *a* basis, was detected at the early afternoon, coincident with the maximum biomass and still high irradiance.

Potential photoinhibition measured as DCMU induced fluorescence also showed a pattern of daily variation (Fig. 2B). Maximum potential photoinhibition took place at the early morning and peaked at 1000 when photosynthesis decreased slightly. However, cells adapted rapidly showing a decrease in potential photoinhibition by 1300, when radiation was quite high. Minimum potential photoinhibition and maximal photoadaptation happened around sunset and medium values were observed by night.

Oxygen consumption was quite changeable along the day, although maximum values were found in the late afternoon and at the first hours of the evening (Fig. 2C). As the C input from the photosynthetic activity is the driving force for the respiratory activity, a direct relationship between both processes was expected to occur. However, oxygen consumption, showed no direct relationship with the photosynthetic pattern. In fact, oxygen consumption was quite high by night, when carbohydrate content in cells is supposed to be minimum, and on the contrary, consumption was low at midday when photosynthesis was maximum. Such discrepancy with the expected results may involve some methodological consideration. Winkler technique can measure the oxygen consumption with the dark bottle at any time in the day. Nevertheless, some oxygen consuming processes such as photorespiration only take place under light conditions, whereas other processes, such as respiration in cyanobacteria are especially stimulated under darkness. For these reasons Winkler technique may not be totally appropriate to estimate respiration.

Movement of *Microcystis* colonies through the watercolumn has been extensively documented in the literature (for review see: Klemer *et al.* 1996). This movement is due to the formation of gas vesicles which increases their buoyancy. Bloom-forming cyanobacteria may regulate their buoyancy by different mechanisms in response to environmental factors. However, the diversity of buoyancy mechanisms involved make difficult to give a single ecological explanation to the observed movements. Although a special role is attributed to polysaccharide storage as ballast.

Our findings do not support the typical explanations about the buoyancy regulation. It is

usually considered that photosynthesis may drive the loss of buoyancy by mean of polysaccharide production and the resulting ballast effect, or by the increase in the osmolites in the cytoplasm, which ,by turgor pressure, are able of breaking down the gas vesicles already formed. However, we found an increment of the buoyancy apparently driven by light through photosynthesis.

Microcystis buoyancy in Akanoi Bay can be explained by photosynthetic adaptation. By night cells remain at the bottom of the watercolumn. As soon as light drives photosynthesis, energy is available for gas vesicles production and buoyancy starts to operate. This flotation process is slow enough to allow photoadaptation, and by the time cells reach the high irradiance layer, potential photoinhibition is minimum since the photosystem adaptation process has been completed, and photosynthesis is maximum. In that way cyanobacteria may optimize its photosynthetic activity by moving within the watercolumn.

References

- Klemer, A. R., Cullen, J. J., Mageau, M. T., Hanson, K. M., and Sundell, R. A. 1996. Cyanobacterial buoyancy regulation: the paradoxical roles of carbon. *J. Phycol.* 32: 47-53.